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Radiological Quality of the Environment

Office of Radiation Programs

May 1976

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Data have been compiled from federal agencies, States, nuclear facilities, and special studies on the following radiation source categories: ambient environmental radiation, technologically enhanced radiation, fallout, uranium fuel cycle, federal facilities, medical, occupational, and industrial radiation, nonionizing radiation, and other miscellaneous sources. For some of these source categories the available radiation dose data were incomplete. However from the available data, it was found that the largest source of ionizing radiation dose to the population was 10 million person-rem from ambient ionizing radiation. The second largest dose was 3 million person-rem from use of radiopharmaceuticals. About 3 million person-rem were also attributed to technologically enhanced natural radiation. Doses from all other source categories, for which data were available, resulted in less than 0.1 percent of the total population dose.

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RADIOLOGICAL QUALITY OF THE ENVIRONMENT

MAY 1976

U.S. ENVIRONMENTAL PROTECTION AGENCY
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Kurt L. Feldmann, editor

Preface

The Office of Radiation Programs (ORP) of the U.S. Environmental Protection Agency (EPA) has a primary responsibility to establish radiation protection guidance and to interpret existing guides for Federal agencies. This responsibility was transferred to the Administrator of EPA from the Federal Radiation Council which was abolished by Reorganization Plan No. 3 of 1970. One of ORP's mandates in carrying out this responsibility is to monitor and assess the impact on public health and the environment of radiation from all sources in the United States, both ionizing and nonionizing. Therefore, ORP has initiated a radiological dose assessment program to determine the status of radiation data nationwide, to analyze these data in terms of individual and population doses, and to provide guidance for improving radiation data. In addition, this program will provide information to guide the direction of ORP by the analysis of radiation trends, identification of radiation problems, and support for establishing radiation protection guidance. The general approach in this program is to make maximum use of available data reported by other Federal agencies, States and nuclear facilities.

This report is part of ORP's dose assessment program for evaluating the radiological quality of the environment. As a prototype effort, this first report is intended only to summarize information available in the open literature. Special emphasis was placed on acquiring recent dose data. For some source categories, dose information was available for calendar year 1975, for others the most recent data goes back to the early 1970's. It is not intended in this initial effort to calculate or extrapolate from existing data to supply missing dose information. Instead, the concern was for the availability of data and what the existing data provides for individual and population dose information. However, gaps in data coverage and areas of inadequate data coverage are identified when found.

The gathering of data on the radiological quality of the environment will be done annually hereafter. Future reports in this series will be able to analyze the data in greater depth with special emphasis on trend analyses. Also as the dose data become better defined more extrapolations to potential health effects will be considered.

1-C

The first issue of this report also includes a summary of data from EPA's Environmental Radiation Ambient Monitoring System (ERAMS) for FY 1975. These data are included here to make the information more readily available, since there is no longer a separate publication for such data. A glossary of terms used in this report is also included.

Since this is a prototype effort, it is realized that the reported data are probably not all inclusive. If the reader knows of other information on radiation source categories that has not been included or which has not been given adequate coverage, we would appreciate having this information brought to our attention for future reports.

W. D. Rowe

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Chapter 1 - Introduction, Summary, and Conclusions

Background

Numerous studies have been conducted in the past by EPA and other agencies to evaluate the impact of individual radiation sources. However, this report represents the first systematic effort to annually evaluate the impact from all sources of radiation, both ionizing and nonionizing. Such an evaluation requires the assembling of a broad data base on radiation exposures, a responsibility unique to EPA. This effort in determining the quality of the radiological environment is one part of ORP's overall Dose Assessment Program.

Objective

This report is intended to fulfill ORP's responsibility for determining individual and total United States population doses from all source categories of radiation. In addition, this information will provide guidance for direction of programs in ORP by analysis of radiation trends, identification of radiation problems, and support for establishing standards.

Approach

The primary effort in this first prototype report has been to identify source categories of radiation. The identified sources have been considered in two general categories; (1) ionizing radiation, and (2) nonionizing radiation. In the ionizing radiation category, sources were further grouped under the headings of ambient environmental radiation, technologically enhanced natural radiation, fallout, uranium fuel cycle, federal facilities, medical, occupation, and other miscellaneous sources. The nonionizing radiation category is mainly concerned with environmental sources.

Literature searches have been conducted for each of these sources and the available data have been organized to provide the following information:

1. General information about each source category and the availability of data.

2. Data base description (includes who reports data to whom, under what authority, and what data are being reported).

3. Status of data base analyses (to indicate what has been done with the data).

4. A summary of dose data for each source category.

5. Comparison of actual dose data reported with estimates from previous publications.

6. Discussion, evaluation of the adequacy of the data base and needed improvements, and conclusions.

Data acquisition

The most cost-effective way for EPA to acquire the necessary data for assessing the radiological quality of the environment is to maximize the use of available data reported by other Federal agencies, States, and nuclear facilities. Thus, EPA does not intend to repeat measurements for acquiring data where other sources may be adequate. It is recognized that the data from other programs may have been prepared for purposes other than ORP's present interest in dose assessment. However, to determine the need for acquiring additional data by ORP, the first step (represented by this report) is to review the available data and evaluate its adequacy. The identification of gaps in the data indicates areas of concern for future dose assessments. At the same time, source categories may be defined for which additional data collection is not warranted with respect to the small dose contribution from that source.

Special effort was made in this report to acquire real data supported by direct measurements. Such data are in contrast to estimates made by extrapolation with numerous assumptions involved. Most dose information falls in the latter category due to the difficulty or cost of direct measurements. Therefore, most of the data available represent the product of several calculations involving an understanding of the radiation source, and the behavior of that source with regard to interaction with the environment and man.

Data validation

Although it is cost effective for ORP to maximize the use of data provided by other agencies, there must also be concern for the quality of that data. Consequently, ORP supports several data validation activities on a continuing basis. First of all, ORP encourages radiation laboratories to participate in a national quality assurance program. EPA operates such a program for radiation measurements at its Environmental Monitoring and Support Laboratory in Las Vegas, Nevada. This laboratory provides standard radionuclide sources, standard reference materials, and cross-check media for intercomparison measurements with any laboratory desiring to participate.

In addition, EPA conducts special field studies at nuclear facilities or other radiation sources in cooperation with State and other Federal agencies. These studies are designed to characterize radiation sources and environmental effects as well as to validate calculated doses and dose models. The use of such models for calculation of doses represents the third activity for data validation. These models are used to check on environmental effects predicted by models or to check the validity of direct measurments.

Scope

This report is intended to include data as current as possible. When the report was initiated, the most currently available data for some source categories were for calendar year 1973. However, as the report developed it became apparent that a number of new source categories were unknown in 1973 and consequently, the most recent data for these sources are for 1975. For other categories, the only available data are for the early 1970's. Because of the time spread of available data, it was decided to compile the latest data available for each source, regardless of the year for which they were determined. Therefore, this report and those of future years will represent a compilation of the latest data available at the time of preparation.

Future efforts

The radiological quality of the environment will be determined on an annual basis. Future reports will update this first effort and place more emphasis on treatment or analysis of available data and trend evaluations. An analysis of environmental concentrations of radionuclides may also be considered in subsequent reports in addition to dose information.

Sources of information

The information for this report was primarily obtained from published reports such as professional society journals, symposium proceedings, and other technical reports. The EPA regional offices were instrumental in obtaining reports of State monitoring activities. Operating and environmental surveillance reports from nuclear power reactors were obtained from the Nuclear Regulatory Commission (NRC). Data for Energy Research and Development Administration (ERDA) facilities were taken from the contractors' annual environmental surveillance reports. Medical x-ray and consumer product information was taken from reports of the Bureau of Radiological Health, DHEW.

Environmental Radiation Ambient Monitoring System (ERAMS) data

In addition to the radiation data provided by other agencies, EPA has its own program for ambient monitoring data. This program is conducted at the Eastern Environmental Radiation Facility (EERF) in Montgomery, Alabama. Analyses are conducted on samples from national networks for air, milk, and water. The data from these analyses are issued quarterly in an internal environmental radiation data report. It is intended at present to summarize data from these quarterly reports on an annual basis. The ERAMS data for FY 1975, in the appendix of this report, represent the first of these annual summaries and as such also represent a prototype effort. It was decided to include the detailed summary in this report to make the data readily available to those interested in the radiological quality of the environment. It is not planned at this time to publish the annual summaries of ERAMS data elsewhere. However, a comprehensive analysis of past ERAMS data is being carried out.

A brief review of earlier ERAMS data is given in chapter 2 to complete that section on ambient ionizing radiation.

Summary

The purpose of this report is to summarize the individual and population doses in the United States resulting from each category of radiation source and to assess these data. When the literature on radiation sources was searched for information, it became readily apparent that an immense amount of data had been published during the past 15 years. It was therefore considered necessary, first to organize the sources into the 25 categories described in this report, and secondly, to summarize the details in a manner whereby the data would reveal meaning and perspective. In doing so, it was also necessary to assume that all the data extracted from the literature were valid.

The individual and population dose data resulting from the various categories of radiation sources discussed in this report are summarized in table 1-1. The information in this table is divided according to whether the primary mode of exposure is external or internal. Exposure to direct radiation from radionuclides in the ground, water, buildings, and air around us, or from radiation-producing machines, such as x-ray equipment and nuclear accelerators is considered external exposure. Exposures of this type usually result in a radiation dose to the whole body of the person exposed. In contrast, internal exposures occur when radioactive materials are inhaled, ingested, or occasionally absorbed through the skin. Internal exposures often result in a radiation dose to particular organs of the body, such as the lung, gastrointestinal tract, or bones.

It is evident from this table that there are radiation sources for which data are either incomplete or not available. Consequently, the discussion and comments in this report are based upon the data which were available at the time of writing during 1975. Also, it is worthwhile noting that although population doses from the different source categories, in general, can be added together to gain a perspective of overall impact, it does not necessarily follow that individual doses can be added together because an individual in one population group generally does not receive the radiation dose common to another population group. For this reason, the data in table 1-1 only show total population doses in the various source categories.

It is apparent from this table that the dose of approximately 10 million person-rem per year from ambient ionizing radiation greatly exceeds each of the other categories of radiation sources. Within this category of ambient radiation, the ionizing component of cosmic radiation and radon-222, polonium-210 and potassium-40 in terrestrial radiation make the greatest contributions to this dose.

The second largest category of population dose for which we have data is from the use of radiopharmaceuticals for medical radiation purposes, which is estimated to contribute approximately 3 million person-rem per year to the population dose. The third largest category of dose is estimated to be from technologically enhanced natural radiation purposes which also contributes approximately 3 million person-rem per year to the population dose. Finally, it is of interest to note that all the doses from all the other source categories for which data are available are less than 0.1 percent of the total population dose.

It is important to note that the population dose values mentioned here are based upon the data available to us at this time. It is quite possible that these values and thus, the relative contributions of population dose from the source categories considered, could change in the future as more information on this subject becomes available.

Table 1-1 ·Summary of dose data from all sources

Source	External		Internal	
	Individual dose (mrem/y)	Population dose (person-rem/y)	Individual dose (mrem/y)	Population dose (person-rem/y)
Ambient ionizing radiation	-	9.7×10^6	-	-
Cosmic radiation	40.9-45	9.7×10^6	-	-
Ionizing component	28-35.3	9.2×10^6	-	-
Neutron component	0.33-6.8	4.9×10^5	-	-
Worldwide radioactivity				
Tritium	-	-	0.04	9.2×10^3
Carbon-14	-	-	1.0	-
Krypton-85	4×10^{-4}	80	-	-
Terrestrial radiation	30-95	-	18-25	-
Potassium-40	17	-	16-19	-
Tritium	-	-	4×10^{-3}	-
Carbon-14	-	-	1.0	-
Rubidium-87	-	-	0.6	-
Polonium-210	[a]13	-	2-3	-
Radon-222	[b]25	-	3.0	-
Technologically enhanced natural radiation	-	-	-	2.73×10^6
Ore mining and milling	-	-	-	-
Uranium mill tailings	-	-	[c]140-14000	[d]2.5-70000
Phosphate mining and processing	-	-	-	-
Thorium mining and milling	-	-	-	-
Radon in potable water supplies	-	-	-	-
Radon in natural gas	-	-	[e]54	2.73×10^6
Radon in liquified petroleum gas	-	-	0.9-4.0	30000
Radon in mines	-	-	-	-
Radon daughter exposure in natural caves	-	-	-	-
Radon and geothermal energy production	-	-	-	-
Radioactivity in construction material	-	-	-	-

Table 1-1 cont. Summary of dose data from all sources

Source	External		Internal	
	Individual dose (mrem/y)	Population dose (person-rem/y)	Individual dose (mrem/y)	Population dose (person-rem/y)
Fallout	[f]∼ 2	-	-	-
Uranium fuel cycle	-	2014	-	-
Mining and milling	-	-	[g]$4.5x10^{-2}$	2.5
Fuel enrichment	[h]0.17	14	[i]4.8-8.0	[j]14
Fuel fabrication	-	-	[k]$2x10^{-3}$	[k]3
Power reactors BWR	[m]54 max	[n]1552	-	-
PWR	[m]<1 max	∼ [n]155	-	-
Research reactors	-	-	-	-
Transportation - Nuclear power industry	-	[o]100	-	-
Radioisotopes	-	[o]<170	-	-
Reprocessing and spent fuel storage	[p]5.8	[p]23	-	-
Radioactive waste disposal	-	-	-	-
Federal Facilities	-	∼ 1.96	-	-
ERDA	[m]13-320	[n]$8x10^{-7}$-1.96	-	-
Department of Defense	< 0.01	-	-	-
Accelerators	[m] 0.04-4	0.42-65	-	-
Radiopharmaceuticals-production and disposal	0.2	[q]0.083	-	-
Medical radiation				
X radiation	[r]20	-	-	-
Radiopharmaceuticals	-	-	-	[s]$3.3x10^6$
Occupational and industrial radiation				
BWR	[t]1230	-	-	-
PWR	[t]1080	-	-	-
All occupations	[u]0.80	-	-	-

Table 1-1 cont. Summary of dose data from all sources

Source	External		Internal	
	Individual dose (mrem/y)	Population dose (person-rem/y)	Individual dose (mrem/y)	Population dose (person-rem/y)
Consumer products	-	~6100	-	-
TV	[v]0.025-0.043	-	-	-
Timepieces	-	~6100	-	-

	Individual exposure ($\mu W/cm^2$)
Nonionizing electromagnetic radiation	
Broadcast towers and airport radars	10
All sources	0.1-1

a Uranium-238 series
b Thorium-232 series
c Lung dose
d Lung-rem/y
e Trachea-bronchial dose
f 50 year dose commitment divided by 50
g Average individual lung dose within 80 km
h Maximum potential exposure
i Maximum potential exposure to lung
j Cumulative exposure within 40 mile radius
k Average individual lung dose within 80 km
m Fence line boundary dose
n Within a radius of 80 km
o Estimated for the year 1973
p For NFS
q Based upon data from 5 institutions
r Millirads/y (genetically significant dose)
s Estimated 1980 dose
t Average occupational exposure/y
u Average exposure for all occupations & 3.7 radiation workers/1000 persons in United States
v 5 cm from TV set; units of mR/h
- = No dose data available

For individuals, the largest dose is derived from technologically enhanced natural radiation which results in 140 to 14,000 mrem per year to the tracheobronchial surface tissue of the lung as a result of inhalation of radon daughter products from uranium mill tailings.

The second largest individual dose is received by individuals through their occupations, approximately 1200 millirem of whole body dose per year. This is the dose normally received by maintenance personnel working around a boiling water nuclear power reactor. The third largest individual dose, approximately 320 millirem per year, would be received by an individual at the boundary of a federal facility. The next largest dose, about 120 millirem per year, is an average value due to ambient ionizing radiation. The individual doses from all other sources were less than half the dose due to ambient ionizing radiation.

As has been mentioned above, the relative contributions from each of the source categories are subject to revision as may be required by new data.

Evaluation of the data base

It is apparent from table 1-1 that most of the results on individual and population doses are based upon calculations which lead to estimated data. It is customary to prefer measured data to calculated data because of the assumption that they are more accurate and reliable. However, frequently, in order to arrive at certain dose information, it is sometimes impractical or impossible to perform any dose measurements. Consequently, under these circumstances, the only possible or cost-effective way of determining the dose to an individual or a population is through dose model computation. This type of calculation generally involves experience and judgment to arrive at order of magnitude estimates which are considered to be satisfactory for dose assessment. For example, it is virtually impossible to measure the dose to an individual from the potassium-40 in the human body. However, data on the potassium-40 concentration in the body, energies and types of radiations, half-life of the radionuclide and mass of the body are available and can be used to compute the dose. Such doses may be considered to be reliable and conservative estimates with the understanding, that in all probability, the values for the actual doses are appreciably smaller than the estimated values.

In determining individual doses, it is important to appreciate the fact that these doses are for specific categories which are additive only if it is reasonable to expect that the same individuals would be exposed to the sources in these categories. For example, in general, the individual dose from uranium mining and milling should not be added to other source categories in the uranium fuel cycle because different individuals are involved in these exposures.

Finally, after searching the literature for individual and population dose values and studying the manner in which many of these values were determined, it becomes evident that frequently, the number of significant figures representing the data cannot be justified. For this reason, the data in table 1-1 are considered valid to about 2 significant figures in spite of the fact that more figures are given in the literature and used in this report.

It is also evident from table 1-1 that many gaps appear in the data. This is apparently due to the fact that some of the information published is oriented toward individual dose, and other data are expressed in terms of concentrations of isotopes in various environmental media. For example, data concerned with phosphate mining and processing operations report that occupational personnel in the industry are exposed to uranium decay chain products which are present in ore with a concentration of 4 to 10 picocuries per gram. It is not possible to obtain an estimate of population dose from these data without considerable supplementary knowledge. For this reason, no dose data are available for this category. It is hoped that these data will be filled in future reports.

In addition to this brief evaluation of the data base, each chapter in the report contains a more detailed evaluation of the data base pertinent to that chapter.

Conclusions

1. On the basis of the population dose data acquired in this report, the three major source categories of radiation dose to the United States population are Ambient Ionizing Radiation, the Application of Radiopharmaceuticals in Medicine, and Technologically Enhanced Natural Radiation. The reason for these relatively high dose values is due to the large populations that are exposed to the sources in these categories.

2. On an individual basis, the largest sources of dose are from Technologically Enhanced Natural Radiation, Occupational and Industrial Operations and Federal Facilities. The factor that keeps the population doses low in Occupational and Industrial Operations and Federal Facilities is the relatively small number of people exposed to the sources in these categories. The source responsible for high individual doses in the category of Technologically Enhanced Natural Radiation is uranium mill tailings that had been used in the construction of residences. It is quite conceivable that if dose from other sources in this category were available, additional high individual doses would be observed.

3. There are many gaps in the dose data of this report. For example, it is generally accepted that the use of x rays in medicine contributes to a large and significant population dose. However, the magnitude of this population dose has still not been determined. For this reason, the resulting observations and comments are necessarily restricted to this data base. It also indicates a need to greatly improve the data base.

Chapter 2 - Ambient Ionizing Radiation

The ionizing radiation dose received from the natural, ambient environment is considered to be composed of three parts: 1. cosmic radiation, 2. worldwide radioactivity, and 3. terrestrial radiation.

Cosmic Radiation

Man's usual environment, the surface of the earth, is continually being bombarded by cosmic radiation. This radiation by definition originates in intersteller space or in the cosmos. However, from time to time the "cosmic" component of our natural radiation exposure is increased by injections of high-energy radiation from our own sun.

The majority of the work reported, by necessity, has been the characterization of cosmic radiation and the measurement of the flux and flux spectra. This work in the United States has been carried out directly by federal agencies, such as the U.S. Atomic Energy Commission, the U.S. Air Force and the U.S. Department of Commerce (National Bureau of Standards); by laboratories such as the Health and Safety Laboratory, Argonne National Laboratory, Pacific Northwest Laboratories, Holifield National Laboratory (Oak Ridge); and by universities such as the University of California (Lawrence Livermore Laboratory and Lawrence Berkeley Laboratory), the California Institute of Technology, and other groups such as the National Academy of Sciences.

The research findings have been reported in all forms. Special committee reports, annual reports, project reports, symposium proceedings, and journals. A partial list of journals include Science, Journal of Geographical Research, Physics Review, International Physics Review, Nuclear Instrumentation & Methods, Review of Modern Physics, Journal of Applied Physics, Nucleonics, and Health Physics.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports of the twentieth, twenty-first, and twenty-second sessions contained in the 1966 and 1969 publications were used to produce the 1972 report. These reports provide excellent literature reviews and state-of-the-art references.

Reports of the dose equivalence (DE) in the literature vary. Even recent dose rate measurements differed, as shown by Oakley *(2.1)*, from 30 to 40 percent and by 30 percent in UNSCEAR (1972) *(2.2)*. Also, much of the literature data is presented without any dose equivalence or quality factor (QF) information and one must infer that a certain QF was used. In some instances, the value after a QF is applied, seems to be reported consistently as mrad instead of mrem.

Variables measured

Actual measurements of the incident radiation intensities have been made for about 40 years; but research work has shown that the present intensities have not changed appreciably for the last 40,000 years, and probably this time is much longer *(2.3)*. In fact, the levels may have remained fairly constant for 10^8 years with maximum increases of 10 percent occurring during the reversal of the earth's magnetic field; the most recent field reversal occurring 700,000 years ago *(2.1)*. There are two components to cosmic radiation, the ionizing component and the neutron component. There are also four variables which affect these two components that have been described. These are variation in time, latitude, barometric pressure, and altitude.

Time

Changes with time over long and short periods have been observed and reported. There is what appears to be a fluctuation of a few percent change over an 11-year period which is in phase with sun spot activity and a large 7-fold increase for a few hours has been noted *(2.3)*; but in general, the integration of the exposure at the earth's surface over a year's period makes the total contribution of such large events small.

Latitude

The latitude effect was the first variable to be described and the overall effect causes about a 2 percent variation throughout the contiguous United States latitudes. The latitude variation observed in the neutron flux is about 15 percent for the United States, but neutrons are a small component of cosmic radiation.

Barometric pressure

The overall variation in barometric pressure has no effect on the long-term estimation of cosmic radiation, but the barometric pressure may vary by 3 percent from day to day. Thus, the barometric pressure variance can represent a source of error in comparing the different values for cosmic radiation that appear in the literature.

Altitude

Because there are many uncertainties in the various measurements made to date, the only variable previously considered by Oakley *(2.1)* was the altitude. The other variables tended to be obscured by the differences between measurement techniques.

Most of the cosmic radiations upon striking the earth's upper atmosphere produce secondary radiations. Actually, very few of the primary radiations penetrate as deep as the earth's surface; thus, the secondary radiations are the major source of man's exposure, and flux intensities increase with increasing distance from the earth's surface.

Neutron component

The poorest knowledge is about the neutron component since the neutron component is more sensitive to time, latitude, and altitude. At sea level, the flux density is small and difficult to measure. The 1972 UNSCEAR report utilized a fluence to dose conversion factor of 4.95 μrad/h for a flux density of 1 neutron/cm^2/s. This was based on averaging the dose rates to a depth of 15 cm for a slab of tissue; 30 cm thick; the maximum dose rate below 1 cm occurs at 1 cm and is 5.25 μrad/h *(2.2)*.

Oakley, for his work, chose the UNSCEAR (1966) 0.7 mrad/y with a quality factor of 8 (QF=8) or 5.6 mrem/y *(2.1)*. The later UNSCEAR (1972) report adopts 0.35 mrad with a QF=6 or 2.1 mrem/y as the average tissue absorbed dose rate at sea level, 40° latitude; but the report cautions that the variations must be borne in mind and that no account is taken of attenuation or buildup due to surrounding structures. Shielding of 50 g/cm^2 can provide a 30 percent reduction in the exposure at sea level *(2.4)*. Also, a recent National Council on Radiation Protection (NCRP) committee report indicates that a QF of 5 should be applied to the neutron component *(2.5)*. The values reported are summarized in table 2-1.

Ionizing component

The ionizing component does not vary greatly at sea level but differences between measurements exist. Oakley *(2.1)* used the average values reported at sea level in the United States (post-1956) and obtained a value of 2.44 ion pairs (I) per cm^3 per second (s) which was equivalent to 4.0 μrem/h or 35.3 mrem/y. The UNSCEAR (1966) value was 29 mrem/y *(2.6)*. The UNSCEAR (1972) report indicated that the work of one researcher appeared inconsistent and adopted a value of 2.14 I/cm^3/s at normal temperature and pressure (NTP). Assuming that each ion pair in air is equivalent to 33.7 eV, the dose in air/I/cm^3/s would be 1.50 μrad/h; thus, the air dose rate adopted was 28 mrad/y or 3.2 μrad/h *(2.2)*. If the radiation is very penetrating, the absorbed dose index

Table 2-1. Doses from cosmic radiation

Component and reference	Dose (mrad/y)	Dose equivalent (mrem/y)	Quality factor used
Neutron dose at sea level			
UNSCEAR (1966) *(2.6)*	0.7	5.6	8
Upton et al. *(2.1)*	0.38	3.0	8
Watt *(2.1)*		6.8	
O'Brien & McLaughlin *(2.1)*		0.33	3
Hajnal et al. *(2.1)*		3.3	
Oakley *(2.1)*	0.7	5.6	8
[40° Lat.] UNSCEAR (1972) *(2.2)*	0.35	2.1	6
[Equatorial] UNSCEAR (1972) *(2.2)*	0.20	1.2	6
NCRP			5
Ionizing component exposure			
Oakley	35.3	35.3(2.44 I/cm^3/s)	1
UNSCEAR (1966)	29	29	
UNSCEAR (1972) (penetrating)	28	28(2.14 I/cm^3/s)	1
UNSCEAR (1972) (muons)	28	31	1.1
Combined			
Oakley (sea level)		40.9	
Klement et al. (August - United States)		45	

I = ion pair

rate is unity; but for other cases, 75 percent of the exposure is due to cosmic ray muons, the factor should be 1.1 or 3.5 µrad/h which would be 31 mrad/y. These reported values are also summarized in table 2-1.

Exposure above the earth's surface

New data are constantly being added and compared with previous literature reports. The origin of the primary cosmic rays has still not been determined. Most of the observed radiation is believed to originate in our galaxy and two distinguishing terms have been adopted: galactic cosmic rays and solar cosmic rays.

Man's activities such as space travel and the development of supersonic transports (SST) have increased the interest in the calculation of exposures at locations other than the surface of the earth. For instance, the neutron component contributions to exposure at sea level is small, but it rapidly increases with altitude and reaches a maximum between 10 and 20 km.

The evaluations of exposure related to high altitude SST travel have indicated that the passenger-rem received will be less than in a conventional jet. Since, although the exposure at the higher altitude is greater, the SST will fly at greater speeds and the trip will take less time in the SST. Thus, an Atlantic crossing by SST is shown to be 2 mrad, while 2.6 mrad has been stated for present day jets *(2.3)*. However, the increased exposure at the higher altitudes may be reflected in the crew exposures. The present jet crew exposure for flying 600 hours is 0.5 rem/y. With SST travel, this would increase to 1 rem/y.

Compared to the galactic cosmic radiation, radiation of solar origin does not contribute significantly to the average dose rate; but during an intense solar flare, dose rates may increase several orders of magnitude *(2.7)*. However, giant flares only last about 10 hours and only occur a few times during each 11-year cycle; thus, if SST aircraft were equipped with radiation detection devices that would alarm when a prescribed action level was reached, the pilot could decrease this altitude until a safe level was reached.

The QF used at the higher altitudes may need to be different. Schaefer, who estimated the 1 rem/y exposure at about 20 km (65,000 feet), used a QF of 8 for the neutron component. His work and others have been reviewed by O'Brien and McLaughlin, who concluded that one can estimate the annual dose-equivalents to passengers and crew; and that they expected to see, "the development of cosmic-ray ionization profiles with altitude for several latitudes, as well as dose and dose-equivalent rate curves" *(2.8)*.

During space travel, persons are exposed to primary cosmic ray particles, the radiation from solar flares, and the intense radiation in the two Van Allen radiation belts. The maximum dose rate inside a 0.7 g/cm^2 shield was reported by Savun et al. to be 22 rad/h (inner belt) and 5.4 rad/h in the outer belt *(2.9)*.

Combined cosmic radiation

The combined cosmic radiation exposure at sea level as presented by Oakley is 4.6 μrem/h or 40.9 mrem/y *(2.1)*. The combined cosmic exposure at sea level, 40° latitude, and NTP as shown by UNSCEAR (1972) is 30.1 mrem/y *(2.2)*. These differences as shown in table 2-1 result primarily because of the use of a different QF.

Other differences such as latitude (Florida to Alaska varies from 30 to 45 mrem/y) and altitude (sea level to 8,000 feet varies from 40 to 200 mrem/y) have been used to produce an average exposure for each county or similar political unit in the United States. This information from Klement, et al. is shown in table 2-2 *(2.10)*. These authors also present estimates of the annual man-rem (person-rem) for years 1960-2000, and for 1970, the value given is 9.2 million person-rem based on United States population of 205 million people *(2.10)*. This is also based on the average of 45 mrem/person in the United States as shown in table 2-2.

The annual passenger-kilometers flown should be approaching 10^{12} (excluding China) since 4.6×10^{11} passenger-kilometers were flown in 1970 *(2.2)*. Assuming a speed of 600 km/h, the total is 10^9 passenger-hours each year. The collective dose for subsonic flights for 1970 was reported to be 250,000 person-rads which corresponds to a worldwide population dose of 0.1 mrad/y/person *(2.2)*. This population exposure compared to the surface exposure is insignificant, however, as previously shown, the cosmic exposure received by certain individuals could be 10 to 20 times the average surface exposure.

Summary

The data concerning ambient ionizing radiation indicate values which represent the best conservative estimates for the whole body dose resulting from cosmic ionizing radiation and its neutron component at sea level. These values are dependent upon latitude, longitude, and altitude above the surface of the earth and can result in increases by a factor of 10 or 20 as the altitude increases above sea level. This is readily seen in table 2-2 where the annual cosmic radiation dose in Florida at sea level is 30 mrem/y and in Colorado, about 1 mile above sea level, where the annual dose is 120 mrem/y.

Table 2-2. Estimated annual cosmic-ray whole-body doses *(2.10)*
(mrem/person)

Political Unit	Average Annual Dose
Alabama	40
Alaska	45
Arizona	60
Arkansas	40
California	40
Colorado	120
Connecticut	40
Delaware	40
Florida	35
Georgia	40
Hawaii	30
Idaho	85
Illinois	45
Indiana	45
Iowa	50
Kansas	50
Kentucky	45
Louisiana	35
Maine	50
Maryland	40
Massachusetts	40
Michigan	50
Minnesota	55
Mississippi	40
Missouri	45
Montana	90
Nebraska	75
Nevada	85
New Hampshire	45
New Jersey	40
New Mexico	105
New York	45
North Carolina	45
North Dakota	60
Ohio	50
Oklahoma	50
Oregon	50
Pennsylvania	45
Rhode Island	40
South Carolina	40
South Dakota	70
Tennessee	45
Texas	45
Utah	115
Vermont	50
Virginia	45
Washington	50
West Virginia	50
Wisconsin	50
Wyoming	130
Canal Zone	30
Guam	35
Puerto Rico	30
Samoa	30
Virgin Islands	30
District of Columbia	40
Total United States	45

Worldwide Radioactivity

Worldwide radioactivity consists of both naturally occurring and manmade radioactivity. The cosmic ray neutrons cause capture reactions in the atmosphere and in the earth's soil and water cover. The nuclides produced in the earth's cover are discussed in the section dealing with terrestrial radiation. The radionuclides produced in the atmosphere are shown in table 2-3. Although table 2-3 summarizes 14 radionuclides, only two of these nuclides are considered to cause any significant exposure: carbon-14 and, to a lesser extent, tritium. Man's surface activities also affect the ^{14}C and ^{3}H concentrations in the atmosphere as well as adding krypton-85. In addition, radon-222 is a component of worldwide radioactivity; but it will be discussed with terrestrial radiation since its precursors are part of the decay chain of the primordial radionuclide uranium-238.

Tritium is produced in the atmosphere by the interaction of high-energy cosmic rays with atmospheric nitrogen and oxygen and it occurs naturally in the earth's surface waters. About 90 percent of natural tritium is found in the hydrosphere, 10 percent in the stratosphere and 0.1 in the troposphere. The amount of tritium produced has been measured as 0.20 ± 0.05 tritons/cm^2/s, which corresponds to an annual production rate of 1.6 MCi/y and to a steady state inventory of 28 megacuries in the biosphere *(2.2)*.

The inventory of tritium has been increased, however, by nuclear explosions, the contributions from the nuclear power industry and the use of tritium in private industry. Before the advent of nuclear energy, environmental levels of tritium were in equilibrium with the rates of cosmic ray production and decay; but tritium levels are now expected to slowly increase because of the release of this nuclide by power reactors and the reprocessing of spent fuel. Jacobs has estimated that, by the year 2000, a worldwide inventory of waste tritium will be 96 MCi. The tritium would mix throughout the hydrosphere, with the oceans and seas representing the largest reservoirs *(2.11)*.

Figure 2-1 shows the estimated world inventory of tritium in the atmosphere and in surface waters. The dose from worldwide tritium depends on the tritium content in food and water which are dependent on the worldwide inventory. Klement et al. estimated the annual whole body dose to the United States population for the period 1960-2000 (table 2-4) *(2.10)*.

Carbon-14

Carbon, one of the elements essential to all forms of life, is involved in most biological and geochemical processes. The radioisotope ^{14}C is produced in the upper atmosphere by interaction of cosmic ray neutrons with nitrogen. Thus ^{14}C is present in atmospheric carbon

Table 2-3 Cosmic ray produced radioactive nuclides (2.2)

Radionuclide	Calculated atmospheric production rate (atoms/cm^2-s)	Half-life	Maximum energy of beta radiation (keV)
^{3}H	0.20	12.3 y	18
^{7}Be	8.1×10^{-2}	53 d	Electron capture
^{10}Be	4.5×10^{-2}	2.5×10^{6} y	555
^{14}C	2.5	5,730 y	156
^{22}Na	8.6×10^{-5}	2.6 y	545 (β+)
^{24}Na	3.0×10^{-5}	15.0 h	1,389
^{28}Mg	1.7×10^{-4}	21.2 h	460
^{26}Al	1.4×10^{-4}	7.4×10^{5} y	1,170
^{31}Si	4.4×10^{-4}	2.6 h	1,480
^{32}Si	1.6×10^{-4}	700 y	210
^{32}P	8.1×10^{-4}	14.3 d	1,710
^{33}P	6.8×10^{-4}	25 d	248
^{35}S	1.4×10^{-3}	87 d	167
^{38}S	4.9×10^{-5}	2.9 h	1,100
^{34m}Cl	2.0×10^{-4}	32.0 min	2,480
^{36}Cl	1.1×10^{-3}	3.1×10^{5} y	714
^{38}Cl	2.0×10^{-3}	37.3 min	4,910
^{39}Cl	1.4×10^{-3}	55.5 min	1,910
^{39}Ar	5.6×10^{-3}	270 y	565
^{81}Kr	1.5×10^{-7}	2.1×10^{5} y	Electron capture

dioxide, in the terrestrial biosphere, and in the bicarbonates dissolved in the ocean. UNSCEAR estimates the average dose through the whole body to be 1.02 mrad/y, with the highest dose delivered to fat *(2.2)*.

The natural production rate for ^{14}C is not well known. If the assumed production rate is 2 atoms/s/cm^2, 0.03 MCi/y would be formed providing a steady state inventory of 280 MCi *(2.2)*. The decay rate was estimated to be 1.81 atoms/s/cm^2; and, although this is less than the production rate, the values are actually considered to be in good agreement because of the uncertainties involved *(2.2)*. It has been estimated that nuclear tests have added 6.2 MCi or 5 percent of the steady state amount of ^{14}C to the atmosphere *(2.2)*.

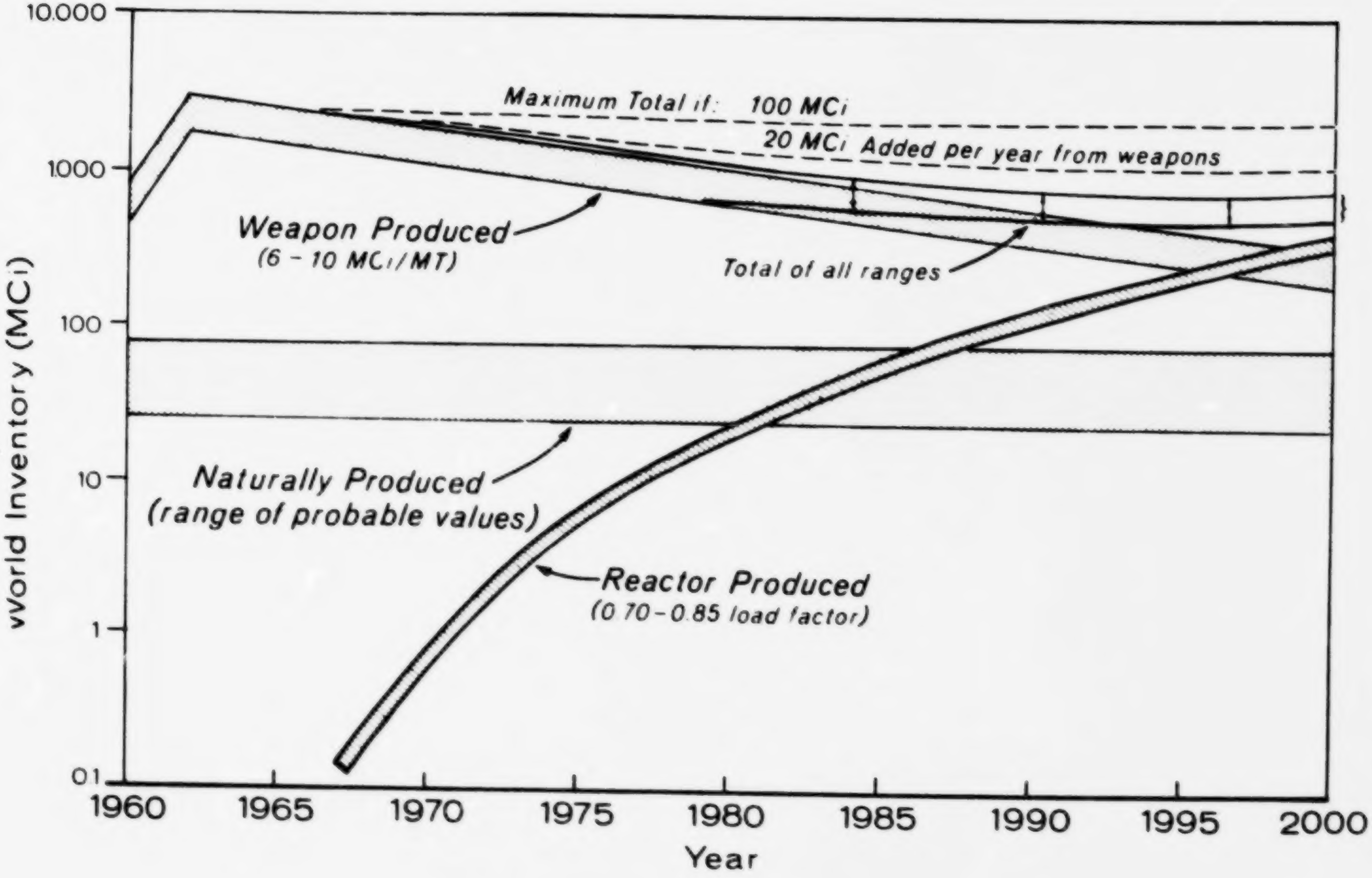


Figure 2-1. Estimated world inventory of tritium in the atmosphere and in surface waters *(2.10)*

The combustion of ^{14}C-free fuel is believed to have caused a decrease in the atmospheric ^{14}C specific activity. The specific activity determined from nineteenth century wood was 6.13 ± 0.03 pCi/g carbon but theoretical reductions (in the absence of nuclear tests) of -3.2 percent in 1950, -5.9 percent in 1969, and -23 percent in 2000 have been calculated *(2.2)*.

Table 2-4. Estimated annual whole-body dose to the United States population from worldwide tritium (*2.10*).

Year	Dose (mrem/person)	Dose to U. S. population (person-rem/y)
1960	0.02	3,100
1970	0.04	9,200
1980	0.03	7,100
1990	0.02	6,700
2000	0.03	8,400

Krypton-85

Krypton is produced artificially by nuclear explosions and by nuclear electric power production. The world inventory from nuclear explosions is calculated to be about 3 MCi *(2.2)*. It was estimated in 1972 that reactors were producing greater than 10 MCi/y. The krypton air concentrations in 1960, 1965, and 1970 were about 5, 10, and 15 pCi/m^3, respectively. Klement et al. calculated annual doses from air concentrations (table 2-5). The estimated krypton-85 concentration in the northern hemisphere from nuclear power production is shown in figure 2-2. Figure 2-3 presents krypton-85 concentrations in the atmosphere as measured by the Environmental Radiation Ambient Monitoring System.

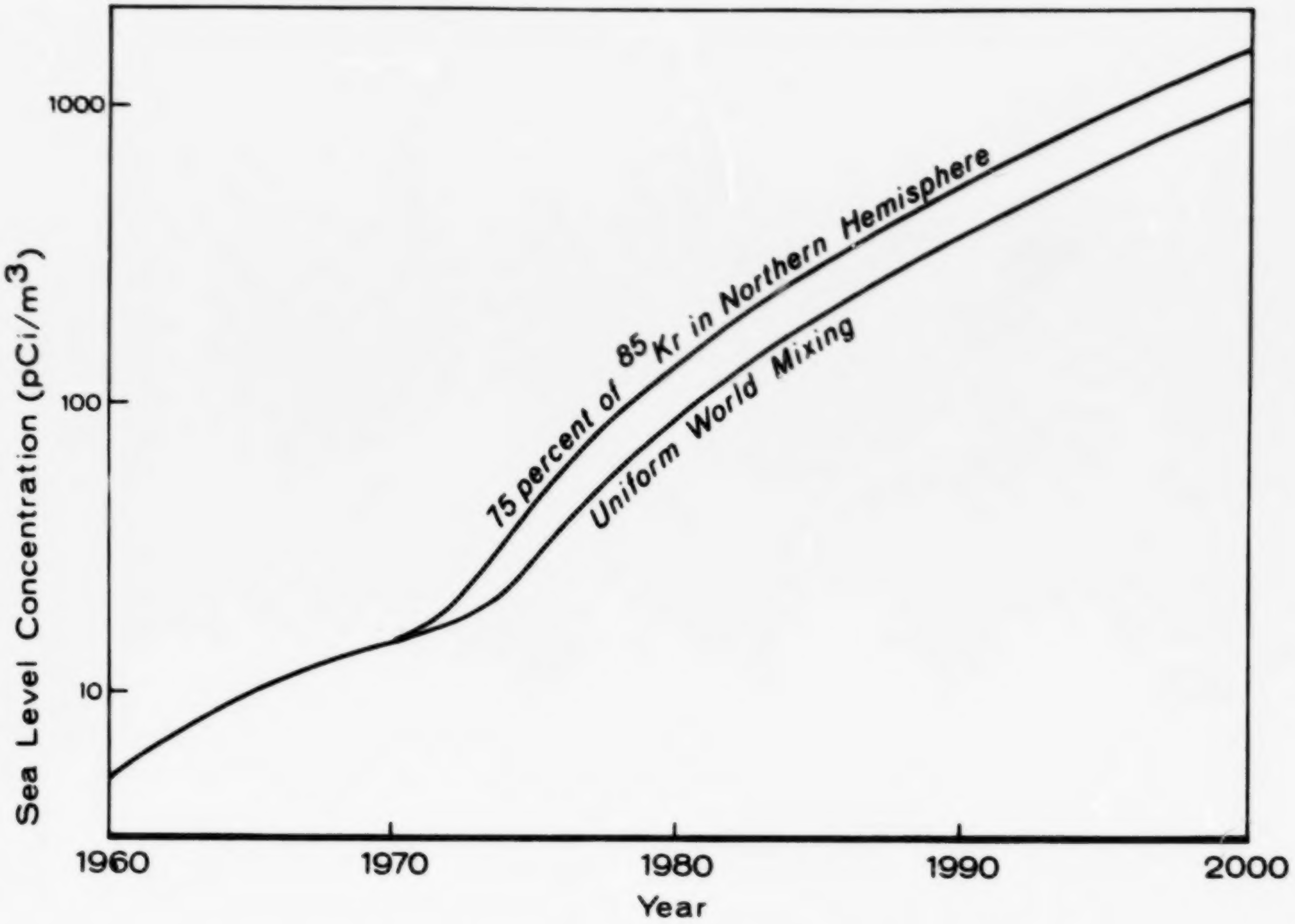


Figure 2-2. Estimated ^{85}Kr concentration in the Northern Hemisphere from nuclear electric power production *(2.10)*

Table 2-5. Estimated annual doses to the United States population from worldwide distribution of ^{85}Kr (*2.10*)

Year	Dose			
	Whole-body (mrem/person)	Whole-body (person-rem)	Skin (mrem/person)	Lung (mrem/person)
1960	0.0001	20	0.005	0.0002
1970	0.0004	80	0.02	0.0006
1980	0.003	700	0.1	0.005
1990	0.01	4,000	0.6	0.02
2000	0.04	12,000	1.6	0.06

Table 2-6. Estimated annual doses to U.S. population from worldwide distribution of selected isotopes

Radionuclide	Individual dose (mrem/y)				Population dose (person-rem/y)	
	External whole body	Internal whole body	Skin	Lung	External whole body	Internal whole body
^{3}H	-	0.04	-	-	-	9200
^{14}C	-	1.0(fat)	-	-	-	-
^{85}Kr	0.004	-	0.02	0.006	80	-

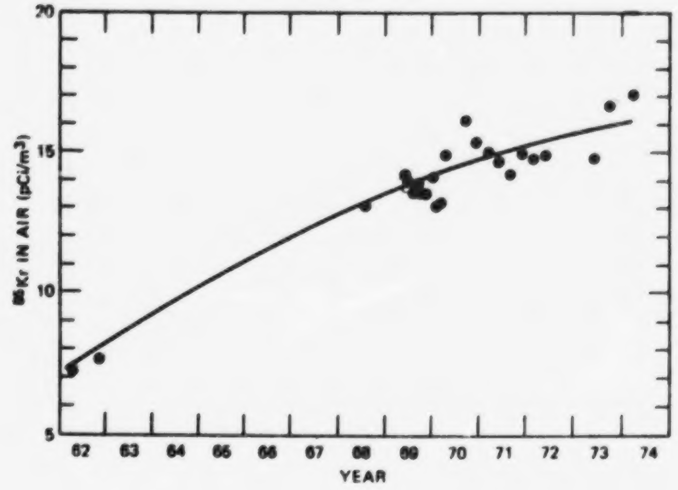


Figure 2-3. Measured krypton-85 concentrations in the atmosphere over a 13-year period *(2.12)*

Summary

Worldwide radioactivity is primarily concerned with the radionuclides, ^{3}H, ^{14}C, and ^{85}K which are produced naturally by cosmic-ray interactions and artificially in nuclear detonations and in the operation of nuclear power facilities. Table 2-6 summarizes the individual and population doses resulting from exposure to these isotopes.

The supplementary data indicate that the concentration of ^{85}Kr in the atmosphere will probably increase by a factor of approximately 100 times present levels during the next 25 years if the current schedule for nuclear power production is maintained. It is estimated that this increase in ^{85}Kr concentration will result in an increase of whole body dose by a factor of 100 and in population dose by a factor of 150. The annual doses from ^{3}H and ^{14}C are considered to be reasonably steady compared to the dose from ^{85}Kr.

Terrestrial Radiation

The naturally radioactive nuclides in man's environment produce exposure by both direct external gamma irradiation and by internal irradiation after entering the body via ingestion and inhalation. Food and water are the main exposure pathways and inhalation is of secondary importance, except for uranium daughters which are discussed later.

The description of the occurrences in the literature and the type of organizations performing the research are the same as described previously for cosmic radiation. Most of the previously mentioned journals such as Journal of Geophysical Research and Health Physics, contain articles and others such as Science, Nature, and the American Industrial Hygiene Association could be added. Reports of the U.S. Geological Survey probably provide the largest single source of area soil composition. Actually, the initial interest in the natural radioactivity in soils was not to determine the human exposure but to determine and locate possible mineral deposits by using ratios of nuclide abundance. The development of age dating techniques was also an early use of natural radioactivity.

The naturally occurring radionuclides may be classified into two groups. The nuclides that are continually being formed by the interactions of cosmic ray particles and matter, and those nuclides which have been present since the formation of the earth, the primordial radioactive nuclides.

Cosmic ray interactions

The presence of cosmic ray neutrons does cause capture reactions in the earth's soil cover, but the exposure from these nuclides is insignificant *(2.1)*. The three nuclides which would probably be the major contributors are beryllium-7, sodium-22 and sodium-24.

Primordial nuclides

The primordial nuclides can be divided into two groups: those which decay directly to a stable nuclide and those that belong to one of three naturally occurring radioactive series. UNSCEAR *(2.13)* and Lowder and Solon *(2.14)* presented data for about 24 radionuclides which exist or were hypothesized to exist. However, most have long half-lives and low abundances; thus, only potassium-40, and the decay chains of uranium-238 and thorium-232 are believed to cause any significant exposure. Rubidium-87 has also been mentioned since its abundance (table 2-7) is much greater than the other nonseries primordial radionuclides.

Table 2-7. Nonseries primordial radionuclides *(2.2)*

Radionuclide	Abundance in the lithosphere (ppm)	Half-life (years)	Alpha or E^a_{max} (MeV)	Gamma[a] (MeV)
^{40}K	3	1.3×10^9	β 1.314(89)	1.460(11)
^{50}V	0.2	$6. \times 10^{15}$	β ? (30)	0.783(30), 1.550(70)
^{87}Rb	75	4.8×10^{10}	β 0.274(100)	
^{115}In	0.1	$.6 \times 10^{14}$	β 0.480(100)	
^{138}La	0.01	1.1×10^{11}	β 0.210(30)	0.810(30), 1.426(70)
^{147}Sm	1	1.1×10^{11}	α 2.230(100)	
^{176}Lu	0.01	2.2×10^{10}	β 0.430(100)	0.088(15), 0.202(85), 0.306(95)

[a] Figures in parentheses indicate yield per disintegration.

The concentration of the primordial nuclides in the soil will be determined by the associated source rock and the subsequent stage of the soil formation process. Igneous rocks generally have more radioactivity than sedimentary rocks and the metamorphic rocks will exhibit concentrations typical for the rock from which they were derived. However, certain sedimentary rocks, shales and phosphate-bearing rocks are highly radioactive *(2.5)*.

Igneous and metamorphic rocks comprise about 90 percent of the earth's crust; but the sedimentary rocks tend to accumulate at the top of the crust, thus, about 75 percent of the earth's surface is covered by sedimentary rocks. In the contiguous United States, the sedimentary rocks, shale, sandstone, or limestone (in a ratio of 3:1:1, respectively), cover 85 percent of the surface *(2.1)*.

The actual environmental exposure produced will depend on the type of rock, the leaching action of water, the porosity of the overburden, the amount of soil or organic material formed on the surface, and the absorption and precipitation of surface deposited radionuclides. Thus, in boggy soils where leaching and humus buildup occur rapidly, the radioactivity concentration is low. It is higher in forests and would be highest, about equal to the corresponding soil-forming rocks, in arid climate soils *(2.4,2.5)*.

Internal irradiation

The principal internal emitters considered are shown in table 2-8. These radionuclides are present in our environment and enter the body with our food and water. Inhalation is of secondary importance except for radon daughters and the immediate areas surrounding some industrial sites such as uranium mills or uranium mill tailings piles.

Potassium-40

The main naturally occurring source of internal radiation exposure has been stated to be ^{40}K. It enters the body primarily in food stuffs and its concentration varies considerably in different body organs. Whole body counting studies indicate persons under 20 years of age contain 15 percent less potassium than persons over 20 *(2.2)*. The reasons for this are not immediately evident and are probably due to a combination of things since the potassium concentrations in different tissues are given as: muscle, brain, and blood cells, 0.3 percent; blood serum, 0.01 percent; and fat, none. Thus, the average potassium content of the body will depend on body build, and obese persons have a lower g K/kg body weight ratio than lean persons *(2.2)*. Females have more fatty tissue than males and, therefore, exhibit lower g K/kg body weight ratios *(2.1)*. Three isotopes of potassium occur; two isotopes, ^{39}K (93.1 percent) and ^{41}K (6.9 percent), are stable. Despite the low abundance of ^{40}K (0.0118 percent), its activity in soil averages an order of magnitude greater than ^{238}U or ^{232}Th *(2.1)*.

Table 2-8. Estimated average annual internal radiation doses per person from natural radioactivity in the United States

Radionuclide	Dose to whole body			Dose to endosteal cells		Dose to bone marrow			Dose to gonads	
	(2.1)* mrem	(2.2) mrad	(2.10) mrem	(2.2) mrad	(2.10) mrem	(2.1) mrem	(2.2) mrad	(2.10) mrem	(2.1) mrem	(2.2) mrad
^{40}K	16	19**	17	6	8	16	15	15	16***	19
^{3}H			0.004	0.001	0.004		0.001	0.004		0.001
^{14}C			1.0	0.8	1.6		0.7	1.6		0.7
^{87}Rb		0.6	0.6	0.4	0.4		0.6	0.6		0.3
^{210}Po	2		3.0	4.0	21	2	0.3	3.0	2	0.6
^{220}Rn							0.05			0.003
^{222}Rn			3.0	0.04	3.0		0.08	3.0		0.07
^{226}Ra				1.6	6.1		0.1	0.3		0.02
^{228}Ra				1.9	7		0.1	0.3		0.03
^{238}U				0.8			0.06			0.03
Total	18	21	25	16	47	18	17	24	18	21

*Reference number

**17 mrad/y from beta and 2 mrad/y from gamma

***Average: 19 mrem/y, male and 13 mrem/y, female.

Rubidium-87

The isotopic abundance of ^{87}Ru is 27.8 percent and is about 17 ppm in the whole body tissues of bone and gonads. The average gonadal dose is calculated to be 0.3 mrad/y and 0.4 mrad/y to the small tissue inclusions within the bone. Assuming that the ^{87}Ru concentrations in bone marrow is the same as averaged for the whole body, the dose to the bone marrow would be 0.6 mrad/y *(2.2)*.

Uranium and thorium series

There are three natural series or decay chains. Two start with radioisotopes of uranium, ^{238}U and ^{235}U. The third series starts with ^{232}Th. These series are shown in tables 2-9 to 2-11. Uranium and thorium are distributed throughout the earth's crust in approximately the same activity concentration. The activity ratio, ^{235}U/^{238}U, in nature is less than 0.05, and the radon isotope in the ^{235}U chain (^{219}Rn) has a very short half life, resulting in atmospheric activities of its decay products which are about 2,000 times less than those of ^{222}Rn; thus, the ^{235}U chain is not considered to cause any significant environmental exposure.

Uranium-238

The uranium-238 chain can be divided into four parts: 1. The long-lived isotopes, ^{238}U, which are considered to be in equilibrium in nature, 2. ^{226}Ra, since its concentrations in the environment and man are not necessarily related to its uranium parents, 3. ^{222}Rn and its short-lived daughters (through ^{214}Po), and 4. the long-lived radon daughters, ^{210}Pb, ^{210}Bi, and ^{210}Po. One gram of natural uranium contains 0.33 μCi ^{238}U and 0.015 μCi ^{235}U *(2.2)*.

Man's uranium uptake in his daily diet has been shown to be 1 μg/d *(2.2)*. The uranium in the soil enters plants and then goes directly into man and herbivorous animals and also into man from herbivorous animals. Water can also provide a source of uranium, and values of 0.024 to 200 μg/ℓ in fresh water are reported *(2.2)*. Uranium, as well as thorium and radium, can be present in air, but normally in very small quantities. Thus, inhalation is not considered to be a source of normal exposure except for radon and its daughters. The exposures calculated for uranium are shown in table 2-8.

Thorium-232

Thorium enters man in the same manner as uranium, and experiments performed with plants showed that thorium was readily absorbed by plant roots; however, no intake values appear in the literature *(2.2)*. It also appears that although thorium is readily absorbed, the concentration in the plant's shoots is negligible compared to radium.

Table 2-9. Uranium (radium) series *(2.15)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Uranium-238	^{238}U	4.5×10^9 y	α	4.18(77), 4.13(23)
Thorium-234	^{234}Th	24.1 d	β	0.19(65), 0.10(35)
			γ	0.09(15), 0.06(7), 0.03(7)
Protactinium-234	^{234}Pa	1.18 min.	β	2.31(93), 1.45(6), 0.55(1)
			γ	1.01(2), 0.77(1), 0.04(3)
Uranium-234	^{234}U	2.50×10^5 y	α	4.77(72), 4.72(28)
			γ	0.05(28)
Thorium-230	^{230}Th	8.0×10^4 y	α	4.68(76), 4.62(24)
Radium-226	^{226}Ra	1622 y	α	4.78(94), 4.59(6)
			γ	0.19(4)
Radon-222	^{222}Rn	3.82 d	α	5.48(100)
Polonium-218	^{218}Po	3.05 min.	α	6.00(100)
Lead-214	^{214}Pb	26.8 min.	β	1.03(6), 0.66(40), 0.46(50), 0.40(4)
			γ	0.35(44), 0.29(24), 0.24(11), 0.05(2)
Bismuth-214	^{214}Bi	19.7 min.	β	3.18(15), 2.56(4), 1.79(8), 1.33(33), 1.03(22), 0.74(20)
			γ	2.43(2), 2.20(6), 2.12(1), 1.85(3), 1.76(19), 1.73(2), 1.51(3), 1.42(4), 1.38(7), 1.28(2), 1.24(7), 1.16(2), 1.12(20), 0.94(5), 0.81(2), 0.77(7), 0.61(45)
Polonium-214	^{214}Po	160×10^{-6} s	α	7.68(100)
Lead-210	^{210}Pb	19.4 y	β	0.06(17), 0.02(83)
			γ	0.05(4)
Bismuth-210	^{210}Bi	5.0 d	β	1.16(100)
Polonium-210	^{210}Po	138.4 d	α	5.30(100)
Lead-206	^{206}Pb	Stable		

[a] Numbers in parentheses indicate percent abundance.

Table 2-10. Thorium series *(2.15)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Thorium-232	^{232}Th	$1.41\text{x}10^{10}$ y	α	4.01(76), 3.95(24)
			γ	0.06(24)
Radium-228	^{228}Ra	6.7 y	β	0.05(100)
Actinium-228	^{228}Ac	6.13 h	β	2.18(10), 1.85(9), 1.72(7), 1.13(53), 0.64(8), 0.45(13)
			γ	1.64(13), 1.59(12), 1.10, 1.04, 0.97(18), 0.91(25), 0.46(3), 0.41(2), 0.34(11), 0.23, 0.18(3), 0.13(6), 0.11, 0.10, 0.08
Thorium-228	^{228}Th	1.91 y	α	5.42(72), 5.34(28)
			γ	0.08(2)
Radium-224	^{224}Ra	3.64 d	α	5.68(95), 5.45(5)
			γ	0.24(5)
Radon-220	^{220}Rn	54.5 s	α	6.28(99+)
Polonium-216	^{216}Po	0.158 s	α	6.78(100)
Lead-212	^{212}Pb	10.64 h	β	0.58(14), 0.34(80), 0.16(6)
			γ	0.30(5), 0.24(82), 0.18(1), 0.12(2)
Bismuth-212	^{212}Bi	60.5 min.	α	6.09(10), 6.04(25)
			β	2.25(56), 1.52(4), 0.74(1), 0.63(2)
			γ	0.04(1), with α 2.20(2), 1.81(1), 1.61(3), 1.34(2), 1.04(2), 0.83(8), 0.73(10), with β
Polonium-212[b]	^{212}Po	$0.30\text{x}10^{-6}$ s	α	8.78(100)
Thallium-208[c]	^{208}Tl	3.1 min.	β	2.37(2), 1.79(47), 1.52, 1.25
			γ	2.62(100), 0.86(14), 0.76(2), 0.58(83), 0.51(25), 0.28(9), 0.25(2)
Lead-208	^{208}Pb	Stable		

[a] Numbers in parentheses indicate percent abundance.

[b] Divide given percentage yields by 1.5 to obtain yield in terms of thorium-232.

[c] Divide given percentage yields by 3 to obtain yield in terms of thorium-232.

Table 2-11. Actinium series *(2.16)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Uranium-235	^{235}U	7.1×10^{8} y	α	4.40(57), 4.37(18), 4.58(8)
			γ	0.18(54), 0.14(11), 0.20(5)
Thorium-231	^{231}Th	25.5 h	β	0.14(45), 0.30(40), 0.22(15)
			γ	0.08(10), 0.03(2)
Protactinium-231	^{231}Pa	3.25×10^{4} y	α	5.01(24), 5.02(23), 4.95(22)
			γ	0.29(6), 0.03(6)
Actinium-227	^{227}Ac	21.6 y	α	4.95(1.2), 4.86(0.18)
			β	0.043(99+)
			γ	0.070(0.08)
Thorium-227	^{227}Th	18.2 d	α	5.98(24), 6.04(23), 5.76(21)
			γ	0.24(15), 0.31(8), 0.050(8)
Radium-223	^{223}Ra	11.43 d	α	5.71(54), 5.61(26), 5.75(9)
			γ	0.27(10), 0.15(10), 0.33(6)
Radon-219	^{219}Rn	4.0 s	α	6.82(81), 6.55(11), 6.42(8)
			γ	0.27(9), 0.40(5)
Polonium-215	^{215}Po	1.78×10^{-3} s	α	7.38(100)
Lead-211	^{211}Pb	36.1 min.	β	1.39(88), 0.56(9), 0.29(1.4)
			γ	0.83(3.4), 0.40(3.4), 0.43(1.8)
Bismuth-211	^{211}Bi	2.15 min.	α	6.62(84), 6.28(16)
			γ	0.35(14)
Thallium-207	^{207}Tl	4.79 min.	β	1.44(99.8)
			γ	0.90 (0.16)
Lead-207	^{207}Pb	Stable		

[a] Numbers in parentheses indicate percent abundance.

Radium

Radium isotopes are present in all soils and will be found in varying equilibrium with its parents. Since uranium and thorium are usually present in about the same activity concentrations, the isotopes of radium, ^{226}Ra and ^{228}Ra, from ^{238}U and ^{232}Th, respectively, will also be present in similar activity concentrations. However, the normal ^{226}Ra concentration may be increased by the addition of phosphate fertilizers.

The average daily uptake of ^{226}Ra in normal background areas is stated to be 1 pCi/g of calcium.

Radon

Radium-226 decays by alpha emission to its daughter, ^{222}Rn, an inert gas having a half-life of 3.8 days. Similarly, radon-220 is the daughter of ^{224}Ra in the thorium-232 decay chain (table 2-10). These gaseous isotopes can then diffuse from the soil into the atmosphere. The atmospheric concentration of these gases and their daughter products depends on many geological and meteorological factors. Because the daughter products of radon and thoron are electrically charged when formed, they tend to attach themselves to the dust particles normally present in the atmosphere, thus becoming the only significant natural radionuclides leading to widespread exposure through inhalation.

Radon can also reach man through water, and the ingestion of 1 μCi of ^{222}Rn dissolved in water has been indicated to cause a 20 mrad exposure to the stomach *(2.6)*. Another source could be milk, but values should be lower (in Sweden, ^{222}Rn concentrations in milk are 40 times less than in water) *(2.2)*.

Long-lived radon-222 daughters

The average concentration of ^{210}Pb for a location will depend on the ^{222}Rn surface exhalation rate at that point and the global pattern of air circulation. The average ^{210}Pb to ^{210}Po ratio will be 10 in the northern middle latitudes. The concentrations would be 15 and 1.5 Ci/m^3, respectively *(2.2)*. However, ratio values of less than unity can be found in industrial areas. This has been attributed to the release of ^{210}Po during the combustion of coal. The standard man inhales 20 m^3 of air per day; thus, for the "normal" areas, 0.3 pCi ^{210}Pb and 0.03 pCi ^{210}Po would be inhaled.

Cigarette smoking causes an additional uptake of lead-210 and polonium-210 as both are present in tobacco; ^{210}Po is more abundant because it is highly volatile. One pack of cigarettes per day causes a daily intake of 0.3-0.8 pCi ^{210}Pb and 0.4 to 1.4 pCi ^{210}Po *(2.2)*. If a lung to blood transfer coefficient of 0.3 is used, 0.2 and 0.3 pCi/d would be the resultant uptake.

The daily intake from the western diet of milk, bread, meat, and vegetables is 1-10 pCi/d ^{210}Pb with a ^{210}Pb/^{210}Po ratio of about one. Persons whose diet consists primarily of fish or meat ingest higher than average concentrations of ^{210}Po. The largest ingestions found occur in the Lapps and Eskimos because of the lichen - reindeer (caribou) - Lapp (Eskimo) food chain. The average intake reported for the Lapp's is an order of magnitude higher than the northern middle latitudes due to the diet of reindeer.

The radiation dose to the body's tissues caused by the long-lived daughters is primarily due to the energetic alpha particles of ^{210}Po. At equilibrium, the beta contribution from ^{210}Pb and ^{210}Bi is 7.5 percent that of the ^{210}Po alpha energy, thus, it is generally neglected.

The whole body exposure attributed to all of the internal emitters is 18-21 mrem/y; the difference between the literature values appears to be the use of an average of male and female ^{40}K exposures *(2.1)* or the male exposure only *(2.2)*. In "normal" areas (designation used by UNSCEAR), the other internal emitters (not including ^{40}K) provide about 2 mrem/y. However, exposures from individual emitters such as ^{226}Ra and ^{210}Po as discussed can vary by an order of magnitude. The gonadal exposure shown for ^{210}Po in table 2-8 is 0.6 mrad/y which is for normal areas in the northern temperate latitudes. The exposure given for the artic regions is 7.2 mrad/y *(2.2)*. The exposure (table 2-8) for ^{226}Ra is 0.02 mrad/y which is for normal areas; but for areas such as Kerala, India, the gonadal exposure stated is 0.2 mrad/y.

External radiation

The naturally radioactive nuclides contribute significantly to man's external exposure. The radiation that causes the largest increment of exposure is generally gamma-ray radiation, but alpha and beta particle radiations also occur. For example, at one meter above the ground, gamma and cosmic rays produce 7 ion pairs/cm^3/s (I) in air, and beta radiation produces 13 I *(2.1)*. Normally, the beta radiation would produce no rem dose to the bone marrow or the gonads; but it is felt that in special situations, such as houses with dirt floors, significant individual exposures could occur.

In the United States, 90 percent of the population receives an annual dose ranging from 30-95 mrem. The average was 55 mrem/y with ^{40}K, the ^{238}U series, and the ^{232}Th series contributing 17, 13, and 25 mrem, respectively *(2.17)*. The radon daughters in air generally do not contribute much to this dose, only 0.1-0.5 μrem/h *(2.1)*. Measurements for many locations have been collected and averages by state obtained to estimate the exposure to the population of the United States. This method produced an average exposure for the United States of 60 mrem/y/person and the various state averages are shown in table 2-12 *(2.10)*. Other measurements and methods have presented averages of 77 mrem/y *(2.18)* and 43.7 mrem/y *(2.1)*.

Table 2-12. Estimated annual external gamma whole-body doses from natural terrestrial radioactivity *(2.10)* (mrem/person)

Political Unit	Average Annual Dose
Alabama	70
Alaska	60*
Arizona	60*
Arkansas	75
California	50
Colorado	105
Connecticut	60
Delaware	60*
Florida	60*
Georgia	60*
Hawaii	60*
Idaho	60*
Illinois	65
Indiana	55
Iowa	60
Kansas	60*
Kentucky	60*
Louisiana	40
Maine	75
Maryland	55
Massachusetts	75
Michigan	60*
Minnesota	70
Mississippi	65
Missouri	60*
Montana	60*
Nebraska	55
Nevada	40
New Hampshire	65
New Jersey	60
New Mexico	70
New York	65
North Carolina	75
North Dakota	60*
Ohio	65
Oklahoma	60
Oregon	60*
Pennsylvania	55
Rhode Island	65
South Carolina	70
South Dakota	115
Tennessee	70
Texas	30
Utah	40
Vermont	45
Virginia	55
Washington	60*
West Virginia	60*
Wisconsin	55
Wyoming	90
Canal Zone	60*
Guam	60*
Puerto Rico	60*
Samoa	60*
Virgin Islands	60*
District of Columbia	55
Others	60*
Total United States	60

*Assumed to be equal to the United States average.

Summary

Terrestrial radiation comes from radioactive materials in the crust of the earth. These materials contribute to man's exposure by direct radiation and by indirect radiation through ingestion and inhalation. The estimated annual, average, individual, internal radiation dose from selected natural isotopes in the United States is given in table 2-9. These data show that the terrestrial radionuclides responsible for the most significant exposures are ^{40}K, ^{238}U chain products, ^{232}Th chain products, and ^{87}Rb. The whole body exposure attributed to all internal radioactive nuclides is estimated to be 18-21 mrem/y.

In the United States, most of the population receive annual external terrestrial radiation doses ranging from 30-95 mrem/y depending upon location with an average of 55 mrem/y. ^{40}K, ^{238}U chain products and ^{232}Th chain products contributed 17, 13 and 25 mrem/y, respectively, to the terrestrial dose.

Environmental Radiation Ambient Monitoring System (ERAMS)

The ERAMS is a surveillance program of EPA's Office of Radiation Programs for measuring levels of radioactivity in air, air particulates deposition, surface and drinking water, and milk in the United States and territories. The samples are collected by Federal, State, or local governments and analyzed at the Eastern Environmental Radiation Facility in Montgomery, Ala. Sources of radiation and population centers were considered in determining the locations of the sampling sites. The main emphasis for ERAMS is towards identifying trends in the accumulation of long-lived radionuclides in the environment, such as plutonium-238, -239, uranium-234, -235, -238, krypton-85, hydrogen-3 (tritium), cesium-137, and strontium-90.

Trends

A tabulation of all raw data from each sampling network is reported quarterly in Environmental Radiation Data by the Eastern Environmental Radiation Facility. A summary of the FY 75 data appears in the appendix of this report. Figures 2-4 and 2-5 depict the trends of radioactivity concentration versus time for each network. An examination of the graphs reveals a yearly cycle of concentrations of radioactivity which are attributable to fallout. This is explained by the atmospheric mixing between the troposphere and stratosphere in the spring of each year. The submicron radioactive particles from the stratosphere are thus pulled down into the troposphere where settling and washout bring these particles to the earth's surface as fallout.

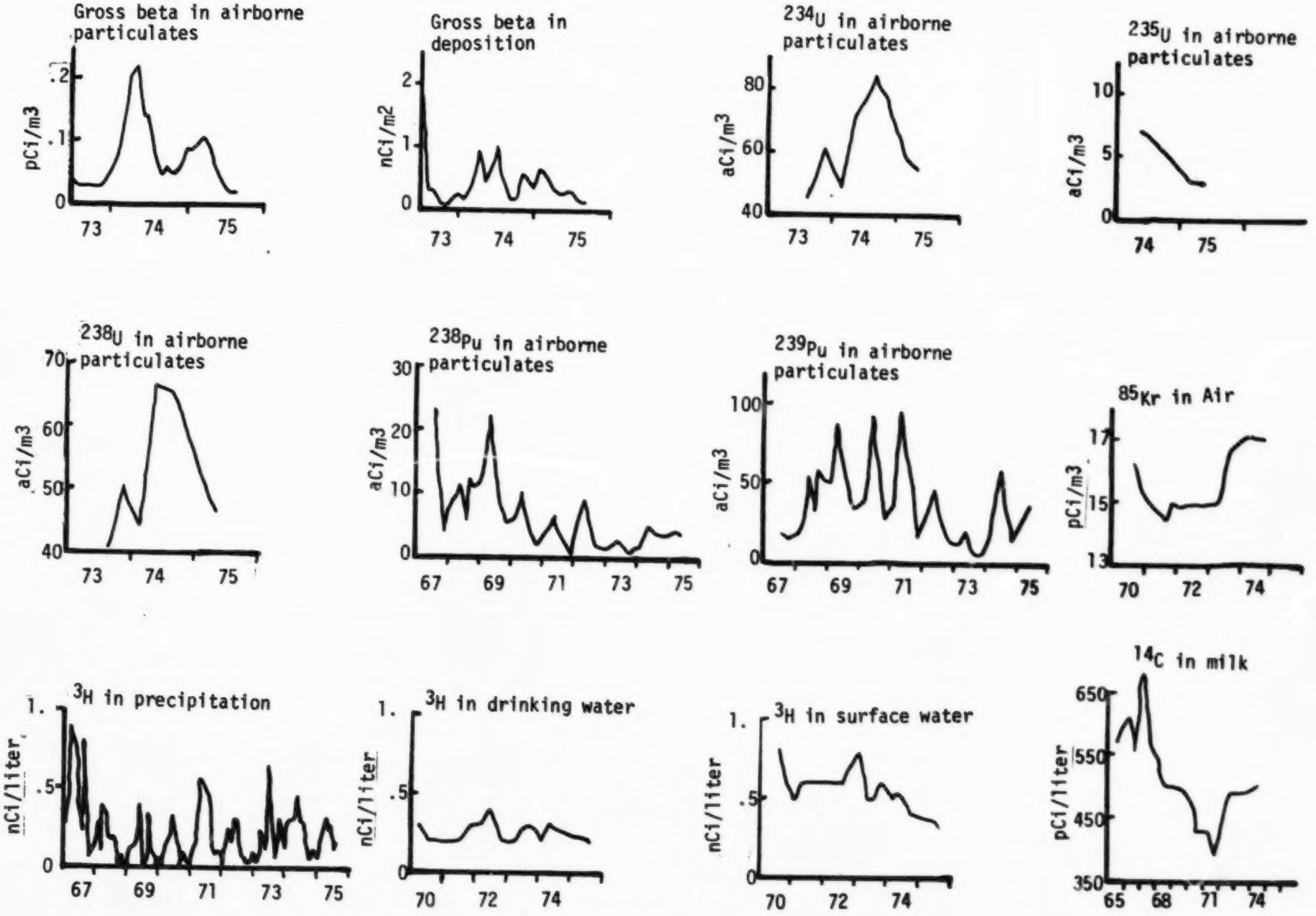
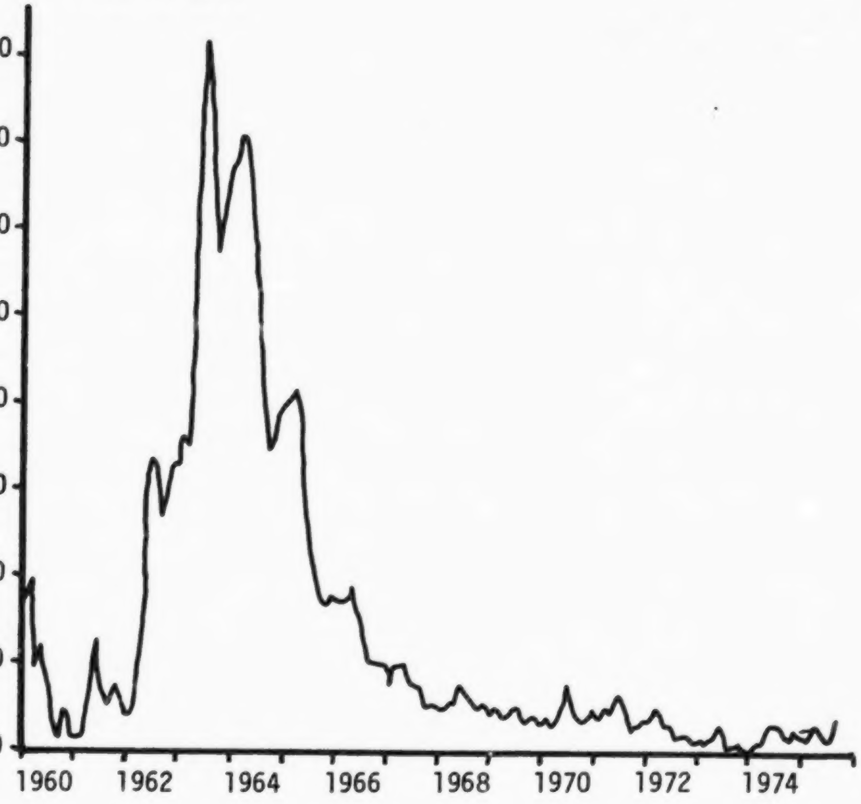
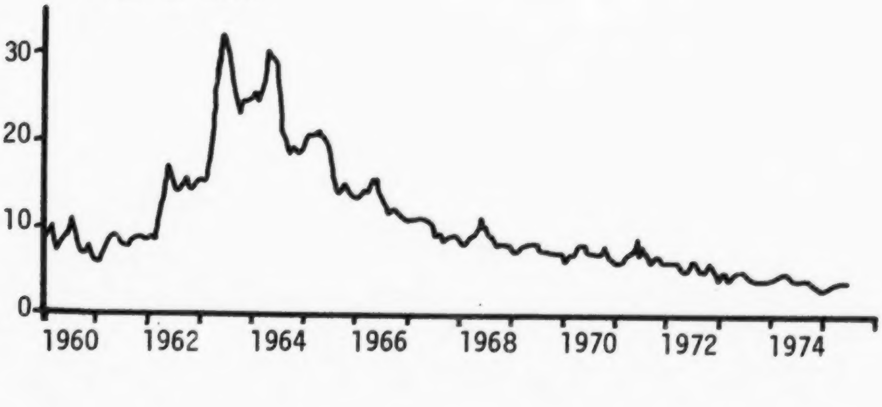


Figure 2-4. Radioactivity concentration versus time



^{137}Cs in milk



^{90}Sr in milk

Figure 2-5. Radioactivity concentration versus time

Radioactivity in air

In the ERAMS Air Program, airborne particulates are collected continuously at 21 sampling stations. An additional 51 sampling stations have been placed on standby. The filters at the sampling stations are changed one or two times per week, and the gross beta radioactivity concentration is measured on each filter in the laboratory. The monthly averages for all analyses are shown in figure 2-4 from July 1973 when the laboratory analyses were reinitiated. The data show a yearly cycle with highest concentrations occurring in the spring and the lowest concentrations in the fall.

The airborne particulates from the 21 air sampling sites are analyzed for uranium-234, -235, and -238. The uranium-234 and -238 concentrations show an increase from 1973 to a peak concentration in mid-1974, and then a decrease extending into 1975. The uranium-235 concentrations show a general downward trend for the short period of time that results are available.

Plutonium-238 and -239 analyses are currently performed on the air particulates from the 21 air sampling sites. However, plutonium-238 and -239 measurements have been conducted since 1967 on samples from selected air particulate sampling stations. The results since 1967 are plotted for both radionuclides and generally show a yearly cycle with the peak concentrations in the spring and the minimum concentrations in the fall.

Krypton-85 concentrations have been measured in air samples collected at 12 locations since 1970. The results for 1970 thru 1974 show very little trend, but in comparison with other measurements made in the 1960's, the general trend is upward.

Radioactivity in precipitation

Gross beta radioactivity measurements are also performed on precipitation samples collected at the 21 air sampling sites. The graph shows the fallout in mid-1973 from a nuclear detonation by the Peoples Republic of China and a spring rise in 1974.

Tritium concentration is measured on a monthly precipitation composite at the same locations as the 21 air sampling sites. The data since 1967 show the yearly cycle of higher concentrations in the summer and lower concentrations in the winter.

Radioactivity in water

Tritium is measured in drinking water at 77 sampling sites which are at either major population centers or selected nuclear facility environs. The data since 1970 show about the same average concentrations.

Tritium is also monitored in surface waters which are downstream from nuclear facilities. The data since 1970 show about the same or slightly declining concentrations.

Radioactivity in milk

The ERAMS milk program consists of 65 sampling stations. Samples from 9 stations were selected for carbon-14 analysis. The results since 1965 show a maximum average concentration in 1967, declining concentrations to a low in 1971, and a general increase since then. There is no readily apparent explanation for the rise and fall of these concentrations.

Figure 2-5 depicts the cesium-137 and strontium-90 concentrations in milk from 1960. Both graphs reflect the fallout from atmospheric detonations in the early 1960's and a decline to present levels.

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Chapter 3 - Technologically Enhanced Natural Radiation

This section deals with exposures received in the ambient environment from materials containing naturally radioactive nuclides. To distinguish the exposure from these materials (which can be controlled) from the exposure received from the natural terrestrial and cosmic radiation sources (generally uncontrollable exposure), the term technologically enhanced natural radioactivity or TENR has been suggested by Gesell and Prichard *(3.1)*.

As stated, this exposure comes from the natural radionuclides; but results from some activity or technology undertaken by man, such as mining or development of wells. Thus, the nuclide is either brought to the surface of the earth where exposures can occur, the surface of the earth which previously provided attenuation or acted as a diffusion barrier is removed, or persons go into the earth in natural caves and manmade excavations. Since some form of technology is involved, the resulting exposure can be controlled; and if the envisioned control measures are cost effective, then it would follow that the exposures should be controlled.

The creation of the TENR classification has been suggested so that agencies with responsibility for issuing guidance for radiation exposures and setting exposure standards can differentiate between natural (background) exposure and the occurrences which were previously referred to as natural radiation anomalies. For instance, if one obtains a gamma radiation measurement of 100 μR/h in Grand Junction, Colo., the extrapolated yearly exposure of 876 mrem/y is not due to background exposure, as it might be in parts of India or Brazil; but the excess gamma (788 mrem/y, assuming 10 μR/h background) is due to TENR (in all likelihood, uranium mill tailings). It is suggested that the development of a TENR category would perhaps do away with the present inconsistent attitude that allows concern for exposure to manmade sources of radiation (radioisotopes and reactors) and ignores the equivalent levels of exposure if they are from a material that was not designed to produce radiation, such as fertilizer. TENR would not be limited to the surface of the earth but would also include such exposures as the exposure received from the cosmic radiation that will be present during supersonic air travel. This too is technologically enhanced natural radioactivity. The sources of TENR which are presently being considered are discussed below, and it is estimated that many technologies may be causing unknown significant exposures.

Ore Mining and Milling

Naturally radioactive nuclides are present in various ores that are not mined for a naturally radioactive element such as uranium. The concentration of the natural radioactive elements will vary even in the same type of ore in different geographic areas. Thus, finding certain concentrations of radium in association with an ore does not necessarily mean that the same type of ore may present a possible health hazard in another geographic location. For instance, the wastes from a fluorspar operation near Golden, Colo., produce gamma radiation levels of about 1 mR/h, and the waste pile is controlled by the State's Division of Occupational and Radiological Health; however, fluorspar ore near Beatty, Nev., produces radiation instrument measurements typical of background levels.

The evaluation of possible radiological health hazards associated with ore and waste products is really just beginning. The fact that the radiation was present in various ores has been known; but by law, unless the ore contained uranium or thorium in concentrations that equal or exceed 0.05 percent (separately or combined), the possession, processing, and disposal of the ore is not licensed or controlled.

Proof that the removal of uranium from uranium ore with less than 0.05 percent remaining in the waste tailings did not render the tailings harmless so that they could be used for construction material, was finally accepted in about 1970.

The EPA and its predecessor programs in the USPHS have been involved with the AEC, the ERDA, and the States in evaluating the possible health effects from uranium mill tailings. The EPA in cooperation with State Health Departments is now in the process of evaluating the products, byproducts, and use of waste associated with the phosphate industry *(3.2,3.3)*.

Other attempts at evaluating other mineral industries have also been started; but the evaluation of the radiation and use of products, byproducts and wastes in these industries will be long and tedious with the current and proposed levels of funding.

Uranium Mill Tailings

The wastes from uranium mills will be discussed in this section and uranium mining and milling will be discussed in a later section dealing with the uranium fuel cycle. These wastes, uranium mill tailings, have been the subject of various investigative research projects since the 1950's, when potable and agricultural water supplies in Farmington, N.M., were determined to have high radium concentrations. The source of this radium was eventually traced to the uranium mill at Durango, Colo., which was located on the Animas River, a tributary of the San Juan River. The wastes from uranium mills, at that time, were usually discharged into a river. This practice was ended, and storage lagoons or tailings ponds came into use. These ponds did not require a new technology since raffinate and pregnant liquor ponds (for mills with dual uranium/vanadium circuits) were already in use.

Little or no sealing or bottom-of-pond preparation was done, since in theory, the fines contained in the tailings slurry were expected to fill in the pores or void spaces in the soil and prevent seepage. In addition, most of the tailings ponds are designed with catchment basins downgradient from the dike or dam where the seepage (that comes to the surface) is collected and pumped back to the pond system. However, the latest reports indicate that seepage is not prevented by "fines-sealing," and in some of the largest mill waste retention systems, about 30 percent of the ponded liquids seep out of the pond and into the surface or ground water *(3.4-3.6)*. At the large mills, 30 percent of the mill effluent can be significant, on the order of 674 million liters per year. It is estimated that this has contributed 1.1 curies of radium to the ground water in the vicinity *(3.7)*.

The ore feed to the mills has been estimated to average 0.25 percent U_3O_8. Usually, the radioactive nuclides of the ^{238}U decay chain are in equilibrium. Thus, the uranium daughters will all have the same activity. This activity may be calculated by multiplying 290 times each 0.1 percent U_3O_8. Thus, 290 x 2.5 = 725 picocuries per gram of tailings (pCi/g). Almost all of the radium and thorium daughters contained in the ore feed eventually are discharged to the waste system. Thus, the uranium mill tailings will contain about 725 pCi/g of radium-226 and thorium-230.

Uranium mill tailings piles are currently categorized as active or inactive depending on the site activity with the following subclassifications:

1. Active (in use). These piles are located at an active uranium mill site and are receiving wastes.

2. Active (not in use). These piles are located at an active site but have been filled and are no longer receiving wastes.

3. Active (other use). The site is in use but not for milling. No longer receiving wastes.

4. Inactive (standby). These sites exist at mills that are not processing ore. The owner has put the mill in "moth-balls" but plans to reopen.

5. Inactive (controlled). Mill buildings may have been dismantled, but the owner is still responsible for the tailings piles under authorities held by a State agency.

6. Inactive (abandoned). No mill owner responsibility (either the land has been sold or returned to the original land owner).

The radioactivity contained in these piles will, if not controlled, migrate to and contaminate the environment through air and water pathways. The magnitude of the possible population exposures, in general, can be estimated for the various classifications depending on the presence or absence of ponded liquid on the surface of the particular tailings pile. As viewed at present, the pathways involved that can result in radiation exposure to the general public from uranium mill tailings are:

1. Whole body gamma irradiation directly from the pile itself or from the deposition of windborne material.

2. Deposition of radionuclides in the body or in an organ of the body because of the ingestion of water or food that has been contaminated by material from the milling operation.

3. Deposition of radionuclides in the body or in an organ of the body because of inhalation, primarily alpha irradiation of the pulmonary region. Deposition in other areas of the body can also occur after inhalation if the material is cleared from the pulmonary region.

If the surface of a tailings pile is covered with liquid, the tailings material cannot be removed by the wind, and the water will slow up the radon being exhaled from the solids below; however, the water may seep out the bottom or the sides of the tailings pond and the radium can enter the environment, or as the water seeps through the underlying tailings solids, additional radium can be dissolved by leaching.

EPA believes that the radiation dose to the pulmonary region of the lung is the critical pathway, but population exposure by the three modes previously mentioned may be prevented by either one or a combination of two different control actions: one, controlling and stabilizing the tailings pile which will also protect the surrounding environment; and two, providing land exclusion areas between the tailings piles and the general population. The second method, although preventing exposure to man, does not protect the immediate environment.

As soon as a tailings pond no longer has liquid being added to it, the tailings begin to dry due to evaporation and seepage. Eventually, the surface will dry, allowing the wind to pick up the particulate material. For this mode, thorium-230 is believed to be the critical nuclide, exceeding the radiation concentration guide in some cases; however, radium-226, polonium-210, and lead-210 are also usually present.

During the constant radioactive decay occurring in all of the three natural chains discussed in terrestrial radiation, an element, which is an inert or noble gas, named radon is formed. The isotopes are ^{219}Rn called, historically, actinon from the uranium-235 chain; ^{220}Rn called thoron from the thorium-232 chain, and ^{222}Rn called radon from the uranium-238 chain.

Uranium-235 is normally present in very small quantities and the half-life of actinon (^{219}Rn) is 4.0 seconds; thus, there will never be much ^{219}Rn exhaled from tailings material. Similarly, thoron (^{220}Rn) also has a short half-life (55 seconds), and thoron would not diffuse very far in tailings material. The subsequent daughters after radon are particulates, thus; upon formation, they will be trapped in the tailings matrix. Because of the low abundance and very short half-lives, these two radon isotopes are not usually considered to contribute to the health effects calculated for uranium mining and uranium mill tailings. However, if one was associated with a material that contained larger concentrations of thorium-232, such as thorium mining or a manufacturing process that utilized thorium, then there might be a hazard created by the thoron daughters.

Radon-222, the radioactive radon isotope from the uranium-238 decay chain, has a relatively long half-life (3.8 days). The elasticity length in the tailings material will be about 1.5 meters, or 1.5 meters of soil will reduce the radon exhalation by about two-thirds (1/e).

Originally, the concern regarding radon was exposure to uranium miners. The radon-222 itself produces only about 5 percent of the radiation exposure (alpha energy) that contributes to the biological hazard. The main hazard comes from the radon daughters, specifically, the short half-life radon daughters. These daughters are ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po. Since more than one nuclide is involved, a total energy unit was developed which precluded having to determine the concentration of each nuclide. This unit, the working level (WL), was also designed to be a safe occupational level of exposure. Thus, at the time of development, a uranium miner could work in an atmosphere containing one WL and the exposure received would be acceptable. (This "safe" level has now been reduced by a factor of 3).

One WL is defined as any mixture of short half-life radon daughters in a liter of air which will ultimately produce 1.3 x 10^5 MeV of alpha energy. Also, 100 pCi of ^{222}Rn per liter of air in equilibrium with its short half-life daughters will produce 1.3 x 10^5 MeV of alpha energy or 1 WL of exposure. Further, if a miner worked 8 hours per day, 5 days per week for a month (actually based on 170 hours of exposure) in a 1 WL atmosphere, then he would receive a one working level month exposure (WLM). This same exposure for one year would be 12 WLM which was originally a "safe" yearly occupational exposure.

The biological hazard data collected to date is from the uranium miner population. However, with the discovery that uranium mill tailings were being used for construction material and knowing that the tailings had a substantial radium concentration, health officials suspected that elevated WL exposures would be present in the homes built with or over tailings because the radon could diffuse through the material used in the structure. Once the radon reaches the inside of a habitable structure, the radon daughters that are formed can lead to elevated exposures of the occupants.

In 1966, it was discovered that uranium mill tailings were being used as backfill for new home construction in Colorado. It was subsequently determined that tailings had been supplied for this purpose since about 1953.

In August 1970, the Public Health Service provided guidance to the State of Colorado concerning gamma radiation and radon daughter exposures. Referred to as the Surgeon General's Guidance, the document provided for an upper level, above which remedial or corrective action was suggested; a lower level, below which no action was believed necessary; and an intermediate region where the decision for action was based on further evaluation of the specific location. The working level guidance values were 0.05 WL and 0.01 WL, and the gamma radiation values were 0.1 mR/h and 0.05 mR/h, upper and lower guides, respectively.

Two computer data bases were developed. Both of these systems are still in use, and printouts are furnished to the users by the EPA routinely and also upon request. The active gamma data base is now operated for the State of Colorado by a Grand Junction ERDA contractor.

The initial surveys were performed by a mobile gamma survey vehicle which belonged to the AEC, and the necessary adaptations for this use were developed by Lucius Pitkin, Inc., (LPI), the prime contractor for the AEC in the Grand Junction Operations Office. By August 1972, surveys of about 90 communities in 10 Western States (Arizona, Colorado, Idaho, New Mexico, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming) were completed by LPI for the AEC. Any anomalies in the natural gamma radiation levels discovered by the contractor were followed up by an EPA field survey team. A report for each community and a State summary of the community surveys were then furnished to the appropriate State agencies.

Studies of the radon exhaled from uranium mill tailings sites were initiated in 1967. The PHS, AEC, and the Colorado and Utah State Health Departments cooperated in a joint project in four communities, Grand Junction and Durango, Colo., and Monticello and Salt Lake City, Utah.

The results of this study indicated that, beyond the distance of 0.5 mile from the tailings pile, the ambient radon level could not be statistically distinguished from the community's background ^{222}Rn level *(3.8)*.

Environmental surveys were also provided for tailings piles at Tuba City, Ariz.; Mexican Hat, Utah; and Monument Valley, Ariz. *(3.9-3.11)*. All of these surveys indicated that the sites should not be used without stabilization of the tailings piles, and that the surface of the pile should not be used or developed.

In 1973, Congress indicated that comprehensive studies should be made of all of the uranium mill tailings piles under an overall plan rather than surveying each pile separately. The above recommendation was accepted, and a joint AEC/EPA Phase I-Phase II project was started.

During April 1974, a report was prepared for the Climax Site in Grand Junction, Colo. This report was used as the format for the other site reports. This was followed by visits to each site by a team consisting of an AEC representative, EPA representatives from the Office of Radiation Programs in Las Vegas and the EPA region concerned, a representative of the concerned State's radiological health program, and when possible a representative of the milling company. Surveys at all of the sites were completed in May, and the Phase I reports were submitted to the Congress in October 1974 *(3.12)*. The sites included in these reports are shown in table 3-1.

The purpose of the Phase II planned work at the inactive tailings pile sites is to determine the costs of various types of remedial action for a particular site. This work will be performed by an architect-engineering firm performed under contract to ERDA. The first Phase II study was started in mid-1975 at the Vitro site in Salt Lake City, Utah.

Predicted doses

Recent studies by EPA have estimated the radiation doses to an individual and the population from radioactivity in a uranium tailings pile *(3.13)*. Table 3-2 presents the results of this study for six inactive uranium mill tailings piles.

Phosphate Mining and Processing

One of the first steps in processing ore is roasting or calcining. During this process, laboratory analysis indicated, about 85 percent of the polonium volatilized. A field effort was started to determine the actual discharge levels and determine the effectiveness of certain control technologies. The results of this effort have been reported by EPA *(3.2)*. Initial field studies were performed in the southeast United States, primarily Florida since, as reported, 91 percent of the phosphate rock mined comes from Florida. Tennessee produces 3 percent, and the

Table 3-1. Phase I inactive uranium mill site reports *(3.12)*

State	Location	Present owner* or former mill owner**	Size of tailings pile (tons)
Arizona	Monument Valley	The Navajo Nation*	
		Foote Mineral Company**	1,100,000
	Tuba City	The Navajo Nation*	
		El Paso Natural Gas**	800,000
Colorado	Durango	Foote Mineral Company*	1,555,000
	Grand Junction	American Metals, Climax Div.**	1,900,000
	Gunnison	Gunnison Mining Co.**	540,000
	Maybell	Union Carbide Corporation*	2,600,000
	Naturita	Foote Mineral Company*	680,000
	Rifle (old)	Union Carbide Corporation*	350,000
	Rifle (new)	Union Carbide Corporation*	2,700,000
	Slickrock (UCC)	Union Carbide Corporation*	350,000
	Slickrock (NC)	Union Carbide Corporation*	37,000
Idaho	Lowman †	Porter Brothers*	90,000
New Mexico	Ambrosia Lake	Phillips 66*	
		United Nuclear**	2,600,000
	Shiprock	The Navajo Nation*	
		Foote Mineral Company**	1,500,000
Oregon	Lakeview	Atlantic Richfield Company*	130,000
Texas	Falls City	Susquehanna Western**	2,500,000
	Ray Point	Exxon, USA*	490,000
Utah	Green River	Union Carbide Corporation***	123,000
	Mexican Hat	The Navajo Nation*	
		A Z Minerals**	2,200,000
	Salt Lake City	Vitro Corp. of America**	1,666,000
Wyoming	Converse County	Phelps Dodge Company*	187,000

***Property owned by Union Carbide but currently leased to the U.S. Air Force.

†No chemical processing was involved at this site. Heavy minerals in the dredge concentrate from placer deposits were upgraded by physical methods.

Table 3-2. Radiation dose rates for selected inactive uranium mill tailings piles *(3.13)*

Tailings pile	Lung dose to bronchial epithelium of critically exposed individual (mrem/y)	Aggregate lung dose rate to the population within 80 km (organ-rem/y)
Salt Lake City, Utah	14,000	70,000
Grand Junction, Colorado	8,100	14,000
Mexican Hat, Utah	1,200	660
Monument Valley, Arizona	140	2.5
Tuba City, Arizona	2,100	470
Shiprock, New Mexico	900	840

remainder comes from the States of Idaho, Missouri, Montana, Utah, and Wyoming. Phosphate deposits also occur in North and South Carolina and Georgia. The development of the deposits in North Carolina is now underway; however, no development is known to be underway in the other two States.

Plants which process the phosphate rock are located throughout the United States; most produce fertilizer. There are three general types of processes, and some plants may only perform one, while others may produce all of the products. If the marketable ore is combined with sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4) and gypsum result. This product is called normal superphosphate. By separation, phosphoric acid is obtained, and the gypsum is sent to a waste "gyp" pile. The "phos acid" can then be combined with marketable ore to produce triple superphosphate fertilizer, or combined with ammonia to produce diammonium phosphate fertilizer. Other plants combine the marketable ore with coke and silica and, in an electric furnace, produce phosphorus, ferrophos metal (FEP), and slag.

All of these products contain varying quantities of natural radioactivity, and the laboratory analyses of the overburden, ore, products and byproducts is continuing at EPA facilities in Las Vegas, Nev. and Montgomery, Ala.

The fact that uranium, thorium and radium occurred in phosphate rock throughout the world has been known for several years, but the information was primarily obtained for geological identification purposes. However, with the realization that radon from uranium mill tailings can cause significant exposures to the general public, these other sources have come under scrutiny by health physicists.

In the United States, thorium and uranium concentrations in phosphate rock range from 2 to 19 ppm (0.4 to 4 pCi/g) and 8-399 ppm (5.4 to 267 pCi/g), respectively *(3.14)*. The highest and lowest concentrations were reported in South Carolina and Tennessee, respectively. In general, higher concentrations are associated with marine deposits. It has also been shown that, as with other ore such as uranium, the uranium or thorium and their daughter products exist in secular equilibrium, i.e. members of the same series will be present in equal activities. The mining and processing of the phosphate ores redistributes these naturally radioactive nuclides among the various products, byproducts, and wastes. Thus, the materials are dispersed throughout the environment.

At present, the wastes (slag, and overburden) are being evaluated to determine their radioactive contribution to the environment. Recommendations against the use of slag in building materials have been provided by the EPA to the State of Idaho. Many foreign countries use waste gypsum for the manufacture of wallboard, and this use is being studied. Although, no waste gypsum is presently known to be used in the manufacture of wallboard in the United States, samples of this product are being imported from other countries for laboratory analyses.

Much of the land mined, for phosphate has been reclaimed by replacing the overburden removed to reach the phosphate ore. Habitable structures built on this reclaimed land are now being evaluated in Florida. To date, measurements have been made in about 125 structures, two-thirds of which were believed to have been built on reclaimed phosphate land *(3.3)*.

In general, the data from this study coupled with existing information indicates that radium-226 concentrations in soil beneath structures significantly affects the radon daughter levels within the structures. The data collected suggests that structures built on reclaimed land have radon daughter levels significantly greater than structures not built on reclaimed land.

Thorium Mining and Milling

The commercial production of thorium in the United States has usually been from monazite sands but a list of facilities has not been compiled nor made available to EPA; thus, thorium mining and milling operations have not yet received extensive study. One, now inactive, operation in Salmon, Idaho, was surveyed during the 1971 EPA mobile and field team gamma evaluations. No use of the waste material from this operation was discovered.

Radon in Potable Water Supplies

Various reported concentrations of radon-222 from analysis of potable water exist in the literature; however, a comprehensive literature search has not been performed in order to determine if the data are comparable or where the different analyses have been performed.

Data have been presented by Dr. Thomas Gesell *(3.15)* and preliminary calculations have been performed by the Office of Radiation Programs *(3.16)*. Dr. Gesell's data showed the following:

1. Approximately 10-15 percent of all United States drinking water supplies and 1/3 to 1/2 of all ground water supplies have radon concentrations greater than 500 pCi/ℓ.

2. Measured radon-222 concentrations in ground water supplies:

State	^{222}Rn (pCi/ℓ)
Maine	53,700 (Avg. of 226 samples)
New Hampshire	2,500 - 1,130,000 (Avg. 101,000 pCi/ℓ for 26 samples)
Washington, North Dakota Montana, Idaho	19-5,600
Utah	400-1,800
Texas	20-27,000
Houston, Tex.	500-2,000 (Ground water = 75 percent of supply)

In the past, exposures from radon-222 in drinking water have been considered because of the ingestion pathway; and to prevent ingestion, aeration has been suggested. However, EPA believes that the radon-222 concentrations in water could cause significant radiation exposures to people; but that this exposure would be due to the short-lived decay products of radon (the radon daughters), and the pathway would be inhalation.

To examine this hypothesis the following assumptions previously determined by EPA were used: *(3.17, 3.18)*.

1. House size = 227 m^3 (8,000 ft^3)
2. Bathroom size = 6 m^3 (200 ft^3) (5' x 5' x 8')
3. Ventilation rate = 1 complete change each hour
4. Radon to radon daughter equilibrium in house = 50 percent
5. Continuous exposure to a radon concentration of 1 pCi/ℓ produces 4 rem/y and 1 working level month (WLM) per year ~16 rem/y.

If the potable water being used in a dwelling contains 500 pCi/ℓ, the resultant ^{222}Rn air concentration could be 0.15 pCi/ℓ. The continuous exposure to this concentration could produce 500 mrem/y to the lung. These are only estimates and are not presently substantiated. Further efforts are being made to evaluate this potential exposure source.

Radon in Natural Gas

Natural gas as a source of radon and cause of subsequent population exposures to consumers has been evaluated by the EPA *(3.19)*. The EPA paper reviews data collected by many authors including Bunce, Barton, Faul and Gesell *(3.20-3.24)*.

Radon in the geological strata in which the gas wells are located diffuses with the natural gas into the wells, and various modes of storage and distribution were considered. These included well head concentration, well production rate, pipeline sources (gas from one area mixing with another area), transmission time, and storage time.

Doses to the bronchial epithelium were calculated assuming that the radon concentration in the gas was 20 pCi/ℓ, that 0.765 m^3 of gas was used in a kitchen range, in a 226.6 m^3 house with one air change per hour. The average air concentration was calculated to be 0.0028 pCi/ℓ and the tracheobronchial dose from unvented stoves and spaceheaters was calculated to be 15 and 54 mrem/y, respectively. The total for the United States was calculated to 2.73 million person-rems per year.

Radon in Liquified Petroleum Gas

Most of the natural gas from well production fields is not distributed directly to consumers. It is first processed to remove impurities and the heavier more valuable hydrocarbons. Methane is the principal constituent of the natural gas. The components ethane, propane and other heavy hydrocarbons are bottled under pressure as liquified petroleum gas (LPG) with propane as the major constituent. This process may remove up to 50 percent of the radon in the natural gas, decreasing an individual's exposure; but overall, there would be no effect on the population exposure.

The exposures estimated in the EPA report, Assessment of Potential Radiological Health Effects from Radon in Liquified Petroleum Gas *(3.18)*, for unvented kitchen ranges and space heaters were 0.9 and 4.0 mrem/y, respectively; 20,000 and 10,000 person-rems/y, respectively or about 30,000 person-rems/y would result.

Radon Daughter Exposures in Natural Caves

Radon and radon daughter measurements have been made in some of the large natural caves located in the United States such as Carlsbad Caverns *(3.25,3.26)*.

These caves are usually characterized by relatively uniform interior temperatures during the year. Thus at times, unfortunately, usually during the winter, there will be an interchange of interior air with outside air, and the radon concentrations in the cave will be diluted with outside air. During the summer though, the outside temperature will probably be higher than inside and very little air exchange should occur. Thus, during the summer when visitor use would be expected to be the greatest, the working level (WL) exposure is also estimated to be the highest. However, use of elevator shafts, etc., could cause different effects, and the effect of barometric pressure changes has not been studied.

During the 3- or 4-hour underground visit, an individual's exposure will probably not be large; but a significant population person-rem per year may result because it is believed that an excess of one million persons visit some of the large caves operated by the U.S. National Park Service each year.

If studies show control methods should be instituted, ventilation would be envisioned as a corrective measure; however, in this case it is suspected that the control measure could eventually destroy the cave features and cave ecology that persons came to view. More work needs to be done on this source of possible radiation exposure.

Radon and Geothermal Energy Production

Energy from geothermal sources has been produced for several years at the Palisades Plant operated by Pacific Gas and Electric (PG & E) in

Northern California. PG & E and the Union Oil Company of California have contracted with the Lawrence Livermore Laboratory (LLL) to determine the radon and radon daughters present in the production and waste streams of a geothermal electric power generator. Radon-222 concentrations in the thousands of pCi/ℓ have been mentioned in the waste streams, but the data have not been released to EPA.

It is suspected that elevated exposures to radon and its daughters would occur at the plant and in the surrounding vicinity. Other environmental pollutants such as noise and toxic gases (hydrogen sulfide) are also associated with this industry.

Investigations of natural thermal areas and hot springs have recently been conducted by the EPA and others. As with the radon in potable water supply investigations, there has been no correlation between the radium and radon concentrations observed in the samples. Areas investigated to date are in the States of Arizona, California, Colorado, Idaho, Oregon, Nevada, New Mexico and Utah.

Radon Mines

Numerous previous metal mine facilities in the Western United States have been utilized as "treatment" centers, at one time, advertising cures for gout, arthritis and various other physical complaints. Today, these facilities by law cannot advertise various cures and depend on testimonials from their clientel and word of mouth.

Surveys were carried out by the EPA in several facilities in Boulder, Mont. During the usual "treatment" procedure, visitors descend into the mine and spend varying amounts of time sitting on benches or playing cards while inhaling the "curative" radon vapors. Some mines are supposedly "salted" with ore to ensure "helpful" radon levels.

The actual number of persons availing themselves of these facilities has not been tabulated, but the numbers would represent a small percentage of the entire population; thus, this source is not thought to produce a significant population dose.

Individual exposures are also limited because the visits to the mine are short (about 3 hours). Reportedly, most of the users come for a week's cure and, thus, would spend only 12-15 hours per year in the facility. However, workers at the facility such as receptionists and guides can receive significant exposure during their 40-hour week. In some cases, the working level month (WLM) exposures exceed the current uranium miner exposure standard of 4 WLM/y *(3.27)*.

Radioactivity in Construction Material

A literature search and discussion of reports of radioactivity in construction material has been prepared by the EPA's Office of Radiation Programs *(3.28)*. The report contains a bibliography of pertinent references that describe the exposure of the population to levels of the naturally occurring radionuclides present in construction materials.

EPA's bibliography on radioactivity in construction materials contains, to a large extent, articles from the early 1950's to the present, since few surveys were reported in the literature prior to 1950. A brief description of important topics dealt with in each article has been provided with the reference source for those articles which have been reviewed.

The summary and conclusions from EPA's report follow:

"Surveys to determine the radioactive content of specific building materials used in the United States have not been reported in the literature. The external dose to the United States population from exposure to natural radioactive materials (exclusive of uranium mill tailings) contained in United States building materials has not been evaluated, and the possibly significant external exposure from the use of byproduct gypsum and fly-ash materials should be evaluated. The effects of various contruction materials on the attenuation of cosmic and terrestrial radiation have been evaluated in a limited number of surveys in the urban area of Boston, Mass., New York City, N.Y., and Livermore, Calif. The measurement of radon and radon daughter product concentrations has only been reported for a few dwellings and several multi-story office buildings in Boston and in several State-owned buildings in North Carolina. This literature search has found a lack of meaningful data for use in evaluating the U.S. population exposure from building materials.

"Conclusions

"1. The article by Hamilton (1971) is the only significant report of data on the radioactivity content of specific building materials.

"2. Radioactivity in building materials used in the United States has received very little attention. Except for the studies to find construction materials of very low background, there are no reports of radiological surveys of any United States building materials which are used by the general population for construction purposes. Also, there are no reports of United States studies on the possible use of byproduct gypsum and fly-ash products for construction materials.

"3. The reports by Solon, et al., (1960); Yeates, et al., (1970 and 1972); and Lindeken, et al., (1971 and 1973) provide the only data on radiation measurements made inside United States buildings.

"4. The reports by Yeates, et al., (1970 and 1972) and Aldrich and Conners (1974) are the only reported data of radon daughter product concentration measurements made inside United States buildings (exclusive of measurements made to study uranium mill tailings material usage).

"5. The documentation of the evaluation of radiological hazards associated with the use of uranium mill tailings materials for construction purposes in the United States has not been reported in the open literature [except for the report by Duncan and Eadie (1974)]."

Summary

Technologically enhanced natural radiation is radioactive material which occurs naturally as an ore below the surface of the earth, but in the process of exploitation, is transferred to the surface, thus affecting the radiation environment. This occurs in mining where subsurface radioactive ores are brought to the surface of the earth, thus not only affecting workers in the industry but potentially increasing the exposure of populations to these materials. One of the most important of these exposures is from uranium mill tailings piles, the individual and population exposures of which are listed in table 3-2.

Phosphate mining and processing

Thorium concentrations in phosphate rock range from 4 to 10.4 pCi/g and uranium concentrations ranged from 5.4 to 267 pCi/g. The highest concentrations were reported in Tennessee. Much of the land mined for phosphate is reclaimed and is being used for home construction. These homes are exposed to radon daughter levels significantly higher than homes not built on reclaimed land.

Radon in potable water supplies

Approximately 10-15 percent of all U.S. drinking water supplies and 1/3 to 1/5 of all ground water supplies have radon concentrations greater than 500 pCi/ℓ. Table 3-3 lists typical ^{222}Rn concentrations in ground water supplies at selected areas in the United States.

Radon in natural gas

Burning natural gas with a ^{222}Rn concentration of 2[illegible] pCi/ℓ gives an average ^{222}Rn air concentration of 0.0028 pCi/ℓ and the tracheobronchial dose from this concentration could reach a maximum of 54 mrem/y. The total person-rems from this source is estimated to be 2.73 million person-rem/y.

Table 3-3. Typical ^{222}Rn concentrations in ground water supplies at selected areas in the United States

State	^{222}Rn (pCi/ℓ)
Maine	53,700
N.H.	2500-1,130,000
Wash., N.Dak., Mont., Idaho	19-5,600
Utah	400-1,800
Tex.	20-27,800
Houston, Tex.	500-2000

Radon in liquified petroleum gas

It has been estimated that unvented kitchen ranges and space heaters operating on liquified petroleum gas would result in a population exposure of about 30,000 person-rem/y for the United States.

Radon daughter exposures in natural caves

Although individual exposures are not large, nevertheless, due to the large population that visits natural caves, a significantly large population exposure could result.

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Chapter 4 - Fallout

This section presents the status of the collection and reporting of fallout data and doses to man from fallout for the year 1973. In those cases where there may be no data specific to the year 1973, data for doses for the latest year before 1973 are presented.

Information presented in this section of the report has been limited to those sources of information that are the most complete and up to date (re the year 1973). These sources are the Health and Safety Laboratory (HASL) fallout program reports and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report. The former provides an extensive source of fallout information in the form of raw data and interpretive comments. The latter provides the most comprehensive source of information on doses resulting from fallout.

Other sources of information on fallout monitoring and various reports on doses do exist; (see the ERAMS summary in this document) however, the inclusion of a discussion of each would be a laborious task which would provide little more information on fallout and doses than is contained in the sources selected for this report.

Health and Safety Laboratory Fallout Program

Every 3 months, the Health and Safety Laboratory (HASL) issues a report summarizing current information obtained at HASL pertaining to fallout.

To present a more complete picture of the current fallout situation and to provide a medium for a rapid publication of radionuclide and trace element data, the quarterly reports often contain information from other laboratories and programs, some of which are not part of the general AEC or ERDA program. To assist in developing, as rapidly as-possible, provisional interpretations of the data, special interpretive reports and notes are included from time to time.

The reports are usually divided into four main parts which are:

1. interpretive reports and notes,
2. HASL fallout program data,
3. data from sources other than HASL, and
4. recent publications related to radionuclide studies.

An appendix to each quarterly report is also published. This appendix contains the results of the analyses of all samples taken under the HASL Fallout Monitoring Program.

Of the four main parts of the HASL reports only the second is fixed in regard to subject matter discussed. The other parts contain subject matter on various subjects as it becomes available. The second part, HASL Fallout Program Data, is comprised of information and data concerning the following fallout program subjects:

1) ^{90}Sr and ^{89}Sr fallout at world ground sites,

2) radionuclides and lead in surface air,

3) Project Airstream,

4) High Altitude Balloon Sampling Program,

5) ^{90}Sr in milk and tap water,

6) ^{90}Sr in diet (Tri-Cities), and

7) ^{90}Sr in human bone.

The ^{90}Sr and ^{89}Sr in monthly deposition at world ground sites activity consists of the collection of precipitation and dry fallout over monthly periods at stations in the United States and overseas. The samples are analyzed for ^{90}Sr and prior to 1971 for ^{89}Sr whenever possible. At present there are 35 monthly monitoring sites in the United States and 90 sites in other countries.

In late 1958 and 1959, the monthly fallout samples were analyzed for ^{90}Sr and ^{89}Sr. The ^{89}Sr measurements were discontinued in 1960 at most sites, resumed in September 1961 and discontinued again in 1971. Between May 1960 and September 1961, the monthly samples were combined on a 2-month basis because ^{90}Sr levels had dropped considerably. In September 1961, analysis of individual monthly collections were resumed.

The results of all analyses are published quarterly. All ratios of ^{89}Sr to ^{90}Sr have been extrapolated to the midpoint of the sampling month.

Calculated values of the concentration of ^{90}Sr in precipitation are given in units of picocuries of ^{90}Sr per liter. The total precipitation in centimeters and the ^{90}Sr deposition in millicuries per square kilometer for data available in a calendar year are listed. The groups or organizations responsible for the sampling are identified. Monthly ^{90}Sr depositions for New York City since 1954 are shown in graphical form to reflect trends since 1954.

The HASL has been collecting surface air particulate samples at stations in the Western Hemisphere since January 1963. The sample filters are analyzed for a number of fission and activation product radionuclides as well as stable lead. The study is a direct outgrowth of a program initiated by the U.S. Naval Research Laboratory (NRL) in 1957 and continued through 1962. The primary objective is to study the spatial and temporal distribution of nuclear weapons debris and lead in the surface air. The present network of sampling stations extends from 76° north to 90° south latitude.

Samples are analyzed for concentrations of gamma-emitting radionuclides ^{7}Be, ^{95}Zr, ^{137}Cs and ^{144}Ce. Radiochemical analyses are conducted to determine concentrations of ^{54}Mn, ^{90}Sr, ^{109}Cd, ^{144}Ce, ^{238}Pu and ^{239}Pu. In samples collected after some French and Chinese atmospheric weapons tests, additional short-lived nuclides were analyzed, such as ^{89}Sr, ^{95}Zr, and ^{141}Ce. As the levels of any of the radionuclides drop to below practical detection limits they are eliminated from the radiochemical program. The results of all analyses (concentrations) are averaged for each month for each station from 1963 through 1973 by HASL.

Project Airstream is HASL's study of radioactivity in the lower stratosphere. An RB-57F aircraft serves as the sampling platform. Airstream missions are usually scheduled for the months of January, April, July and October of each year. The first Airstream mission was flown in August 1967. Because of budgeting and other compelling considerations Project Airstream as presently structured will be discontinued after the April 1974 mission.

The route followed by the sampling aircraft extends from 75° N to 31° S latitude (Alaska to southern tip of South America). Air filter samples are collected along the flight track. A gamma analysis of the samples is made as well as detailed radiochemical analysis which includes some of the following nuclides; ^{89}Sr, ^{90}Sr, ^{210}Pb, ^{210}Po, ^{238}Pu, and $^{239,240}Pu$. Results of the analyses are reported in HASL's "Fallout Program Quarterly Summary Report."

Under the HASL Fallout Program, HASL operates a High Altitude Balloon Sampling Program. Upper atmospheric nuclear debris are collected by balloon-borne filtering devices. The program has been in operation since 1957. Balloon flights are made at three or more altitudes from 21 km up to a maximum of 42 km from approximately 6 locations.

The sampling filters from the balloon-borne samplers are analyzed for gamma activity as well as radiochemically for long-lived weapons-related radionuclides. These nuclides include ^{89}Sr, ^{90}Sr, ^{238}Pu, and ^{239}Pu. Starting in fiscal year 1973, some samples were also analyzed for ^{210}Pb, and ^{210}Po to compliment Project Airstream studies. The results of the sample analyses are published quarterly in HASL's "Fallout Program Quarterly Summary Report."

HASL has analyzed New York City milk and tap water on a monthly basis since 1954 to determine both tabularly and graphically and published quarterly. The graphical presentation describes the trends in levels since 1954.

HASL performs quarterly estimates of the annual dietary intake of ^{90}Sr of New York City and San Francisco residents. These estimates are based on the analyses of food purchased at these cities every 3 months since 1960. Available data are published in HASL's quarterly summaries. An evaluation of the 1973 data was presented in HASL's Fallout Program Quarterly Summary Report for July 1, 1974.

HASL analyzes specimens of human vertebrae from New York City and San Francisco to determine ^{90}Sr concentrations. Human vertebrae specimens are also received, through the World Health Organization, from countries where western world-type diets are not typical. Analyses are published quarterly. Strontium-90 data for samples received in 1973 were reported in HASL's Fallout Program Quarterly Summary Report for April 1, 1974.

Interpretation of HASL fallout program data

Periodically, HASL publishes interpretive reports and notes concerning the data obtained from the fallout program. Generally, the reports and notes show the results of the last year's data and compare it to data from previous years. Occasionally, doses to man may be calculated. The following reports and evaluations were published by HASL for each of the indicated fallout program areas.

^{90}Sr and ^{89}Sr deposition at world ground sites

Each year since 1958 an estimate of the annual worldwide deposition and the cumulative deposit of ^{90}Sr, based upon data of the HASL sampling network, has been made. All of the primarily monthly precipitation and radiochemical data are listed and updated quarterly in the appendix to each HASL Fallout Quarterly Summary Report. Additionally, a summary of these results, averaged over a 10-degree latitude band was published for 1973 *(4.1)*.

To determine worldwide deposition, HASL assumes that within the 10 degree latitude band, that HASL sampling sites, on the average, are representative of fallout in that area. Hence, multiplying the average monthly ^{90}Sr deposition (mCi/km^2) by the area of the latitude band (km^2) gives the total deposition in that band. For poleward areas beyond 80° N and 70° S, values of deposition are obtained by extrapolating a smoothly decreasing ^{90}Sr deposition to zero at the poles. Summing all the derived deposition in each latitude band yields the total worldwide deposition. The total deposition of ^{90}Sr fallout on the earth's surface in 1973 was found to be 63 kCi. This is the lowest value since the program began in 1958. The seasonal and latitudinal variations in fallout have remained as before *(4.1)*.

Table 4-1 and figures 4-1 and 4-2 show the annual cumulative worldwide ^{90}Sr deposition, monthly ^{90}Sr deposition and cumulative ^{90}Sr deposition since 1958. From these tables and figures, it is evident that the total ^{90}Sr burden is decreasing as radioactive decay exceeds fallout.

Strontium-90 in diet

Estimates of intake via the total diet in New York City and San Francisco have been made since 1960 based upon concentrations found in quarterly food samples. The dietary intakes of ^{90}Sr have decreased from maximum levels attained in 1963-64, but the decline has become more gradual in recent years due to the continuing small amounts of ^{90}Sr deposition and the little changing cumulative deposit in the soil. The annual intake in New York City in 1973 was 9.7 pCi/day which is a 9 percent decrease from 1972. The 1973 estimate of intake for San Francisco was 3.2 pCi/day compared to 3.6 pCi/day in 1972. Lower intakes occurred in San Francisco due to the fact that less deposition occurs in the San Francisco food-producing region *(4.2)*.

Table 4-2 shows ^{90}Sr concentrations found in the diet for some 19 food products in San Francisco and New York City. Figure 4-3 shows the trend in ^{90}Sr concentration in these cities since 1960. The rapid decline in ^{90}Sr intakes after 1963-1964 became more gradual after 1966-67 as the uptake from the little changing cumulative deposit of ^{90}Sr on soil became the dominant factor contributing to ^{90}Sr concentrations in food *(4.2)*.

Resumption of atmospheric testing by the French and Chinese in 1966, resulting in a relatively constant low fallout rate of ^{90}Sr, has been a factor in maintaining the dietary intakes of ^{90}Sr at about constant levels since 1968.

Table 4-1. Annual-cumulative worldwide ^{90}Sr deposition *(4.1)*

Year	Annual deposition (MCi)			Cumulative deposit (MCi)		
	Northern Hemisphere	Southern Hemisphere	Total	Northern Hemisphere	Southern Hemisphere	Total
Pre-1953				1.7	.6	2.3
1958	.630	.255	.885	2.28	.84	3.12
1959	1.052	.185	1.237	3.26	1.00	4.26
1960	.262	.168	.430	3.44	1.14	4.58
1961	.351	.174	.525	3.70	1.29	4.99
1962	1.444	.264	1.708	5.04	1.51	6.55
1963	2.622	.308	2.930	7.51	1.78	9.29
1964	1.656	.422	2.078	8.96	2.16	11.12
1965	.774	.357	1.131	9.50	2.46	11.96
1966	.328	.207	.535	9.59	2.60	12.19
1967	.169	.110	.279	9.52	2.65	12.17
1968	.195	.102	.297	9.48	2.68	12.16
1969	.147	.141	.288	9.40	2.76	12.16
1970	.206	.128	.344	9.37	2.82	12.19
1971	.188	.150	.338	9.33	2.90	12.23
1972	.086	.096	.182	9.18	2.92	12.10

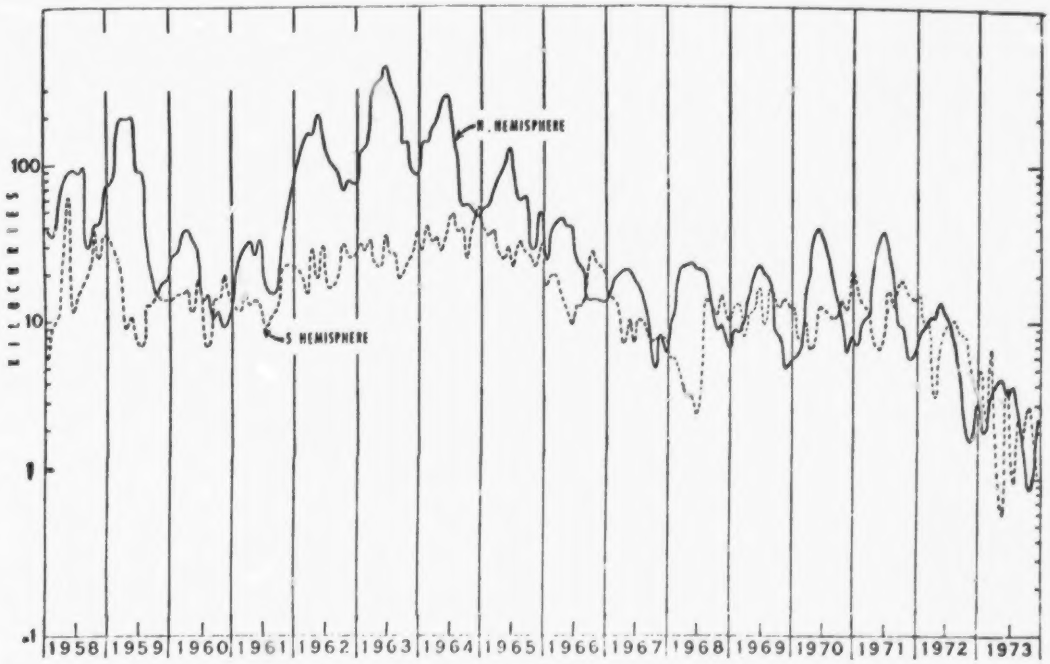


Figure 4-1. Monthly ^{90}Sr deposition *(4.1)*

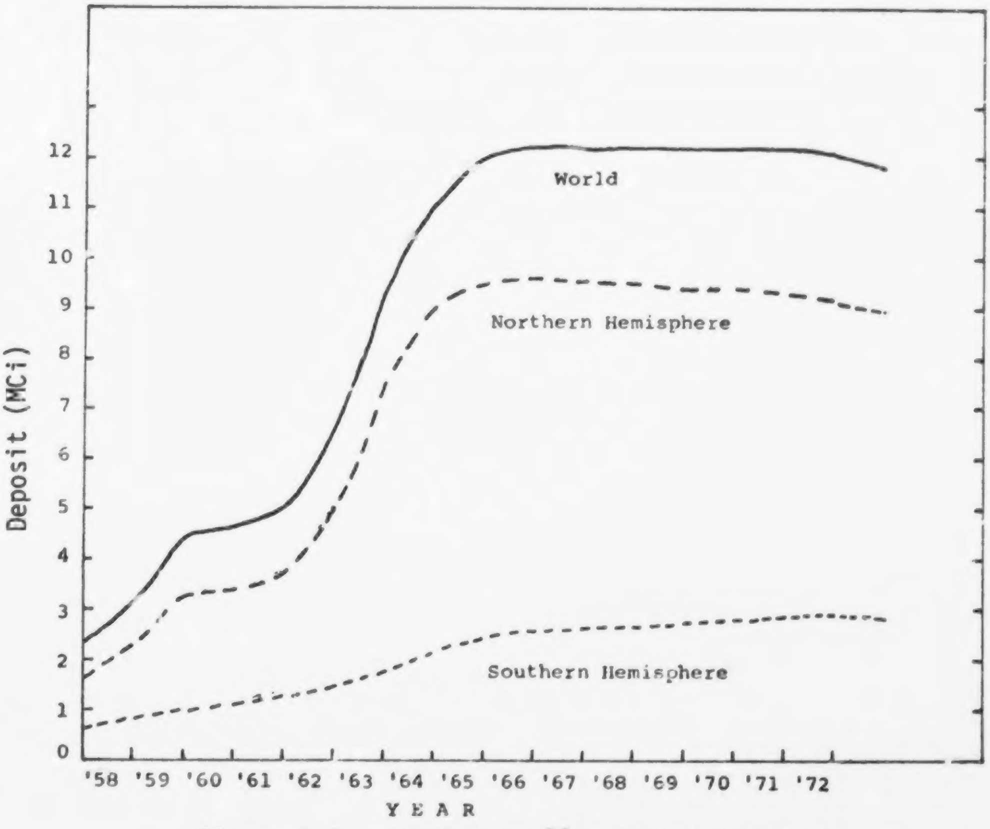


Figure 4-2. Cumulative ^{90}Sr deposition *(4.1)*

Table 4-2. Strontium-90 in the diet during 1973 *(4.2)*

Diet category	kg/y	g Ca/y	% of yearly intake of Ca	New York City pCi ^{90}Sr/kg	pCi ^{90}Sr/y	% of yearly intake of ^{90}Sr	San Francisco pCi ^{90}Sr/kg	pCi ^{90}Sr/y	% of yearly intake of ^{90}Sr
Dairy products	200	216.0		5.5	1090		1.2	246	
			58			31			21
Fresh vegetables	48	18.7		13.1	627		2.7	129	
Canned vegetables	22	4.4		8.7	192		4.3	95	
Root vegetables	10	3.8		7.1	71		3.1	31	
Potatoes	38	3.8		5.5	209		2.7	104	
Dry beans	3	2.1		16.7	50		14.7	44	
			9			32			35
Fresh fruit	59	9.4		11.0	649		2.3	137	
Canned fruit	11	0.6		1.2	13		1.1	12	
Fruit juices	28	2.5		3.0	85		1.5	43	
			3			21			16
Bakery products	44	53.7		4.2	185		2.6	113	
Flour	34	6.5		5.5	186		2.8	96	
Whole grain products	11	10.3		8.5	93		5.6	62	
Macaroni	3	0.6		3.8	11		2.8	8	
Rice	3	1.1		1.7	5		1.4	4	
			20			14			24
Meat	79	12.6		0.6	46		0.2	19	
Poultry	20	6.0		0.7	14		0.4	8	
Eggs	15	8.7		1.5	22		0.8	13	
Fresh fish	8	7.6		0.7	5		0.3	3	
Shellfish	1	1.6		1.2	1		0.6	1	
			10			2			4
Yearly intake		370.0 g			3554 pCi			1168 pCi	
Daily intake					9.6 pCi/g Ca 9.7 pCi/day			3.2 pCi/g Ca 3.2 pCi/day	

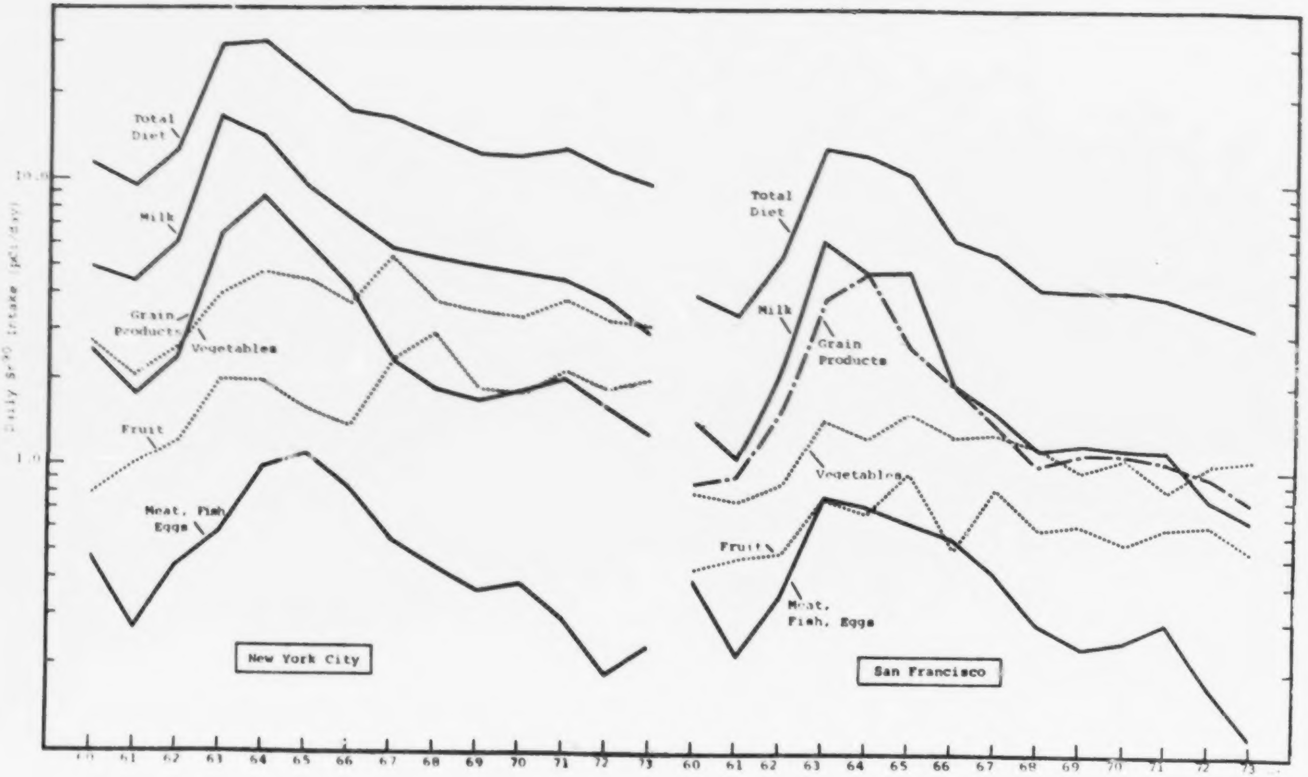


Figure 4-3. Strontium-90 intake in New York City and San Francisco *(4.2)*

Strontium-90 in human bone

Based upon their analysis of human vertebrae specimens, HASL *(4.1)* has reported determinations of ^{90}Sr concentrations obtained during 1973 and the trend in concentrations since 1954. Additionally, results of ^{90}Sr concentration in diets are compared to vertebrae concentrations to determine correlations between ^{90}Sr intake and bone concentrations.

During 1973, 229 specimens of human vertebrae were analyzed, including 43 from children and 54 from adults in New York City and 63 from children and 69 from adults obtained in San Francisco.

Figure 4-4 shows ^{90}Sr in adult vertebrae since 1953 for New York and San Francisco. The decrease since 1965 is consistent with lower levels of ^{90}Sr fallout deposition. The solid lines in figure 4-4 indicate predictions made by HASL using modeling techniques *(4.3)*.

Fallout ^{239}Pu dose to man

Based upon air concentrations (measured and inferred) of ^{239}Pu in New York City, inhalation intake by man, and the ICRP Task Group lung model, Bennet *(4.4)* has estimated ^{239}Pu dose to man through the year 1972. It was assumed in performing model calculations that fallout ^{239}Pu was attached to 0.4 μm aerosol particles and that the inhalation rate was 20 m^3/d or 7300 m^3/y. Table 4-3 shows the yearly computed burdens in man for the period 1952-1972. Figure 4-5 shows the yearly ^{239}Pu intake and the cumulative burdens from 1952 through 1985. The cumulative intake through 1972 was 42.1 pCi.

The doses due to the cumulative intake of 42.1 pCi through 1972 were computed to be 15, 500, 4, and 7 mrem for the lung, lymph, liver, and bone, respectively. If one assumes that the average air concentration will be 0.01 fCi/m^3 in 1973 and that no further intake occurs beyond 1973, the cumulative doses through the year 2000 are 16, 950, 17, and 34 mrem for the lung, lymph, liver, and bone, respectively.

Comparison of the computed organ burdens against results of analyses of autopsy tissue by HASL shows that reasonable estimates of organ burdens from ^{239}Pu inhalation can be obtained from air concentrations and the ICRP Task Group model.

Fallout ^{239} ^{240}Pu in the diet

Although inhalation intake of ^{239}Pu adequately accounts for organ burden, HASL investigated *(4.5)* the occurrence of plutonium in the diet because of the long half-life involved and the persistence of plutonium in the environment.

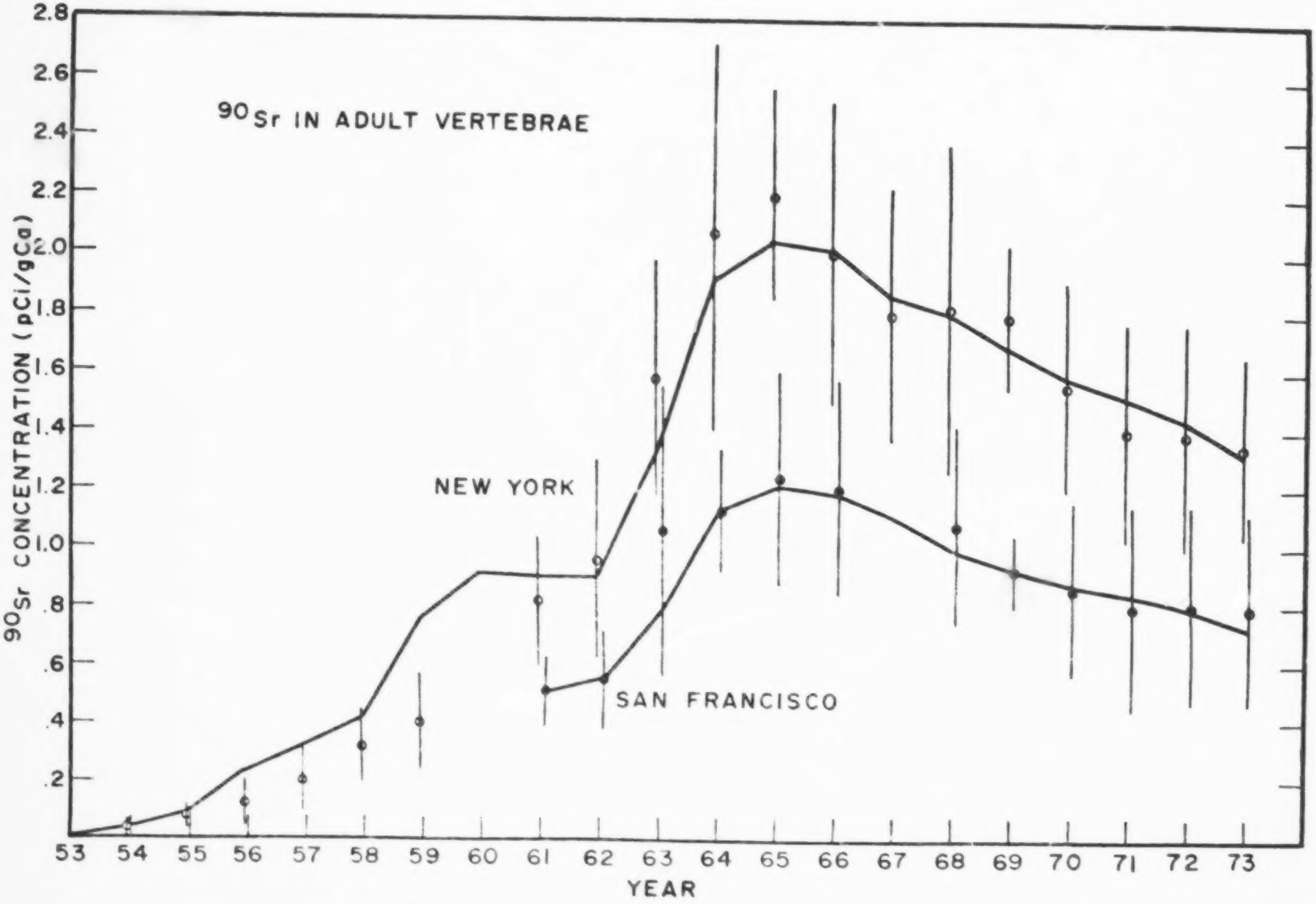


Figure 4-4. ^{90}Sr in adult vertebrae - observations (points with standard deviations) and bone model predictions (solid lines) *(4.3)*

Table 4-3. Fallout ^{239}Pu Data - New York *(4.4)*

Year	Deposition (mCi/km^2)	Cumulative deposit (mCi/km^2)	Surface air (fCi/m^3)	Inhalation intake (pCi)	Computed burden in man (pCi)				
					Lung	Lymph	Liver	Bone	Total body
1954	.07	.07	.14	1.03	.15	.01	.00	.00	.17
1955	.09	.16	.18	1.34	.29	.03	.01	.01	.35
1956	.12	.28	.23	1.66	.43	.07	.02	.02	.54
1957	.12	.40	.23	1.66	.51	.11	.04	.04	.70
1958	.16	.56	.32	2.31	.66	.16	.07	.07	.95
1959	.23	.78	.45	3.25	.89	.21	.10	.10	1.31
1960	.04	.82	.081	.59	.63	.26	.14	.14	1.16
1961	.06	.89	.13	.91	.52	.27	.17	.18	1.14
1962	.32	1.21	.63	4.61	1.01	.31	.21	.22	1.75
1963	.62	1.83	1.68	12.23	2.46	.46	.29	.30	3.50
1964	.41	2.24	.91	6.65	2.48	.65	.39	.40	3.93
1965	.14	2.38	.33	2.39	1.86	.78	.49	.51	3.63
1966	.05	2.43	.12	.90	1.25	.81	.58	.61	3.25
1967	.04	2.47	.051	.37	.81	.78	.66	.69	2.95
1968	.04	2.51	.080	.58	.58	.72	.73	.77	2.79
1969	.06	2.57	.063	.46	.42	.65	.78	.83	2.68
1970	.03	2.60	.065	.47	.32	.59	.83	.88	2.62
1971	.03	2.63	.060	.44	.26	.54	.86	.92	2.58
1972	.02	2.65	.031	.22	.19	.48	.89	.95	2.51

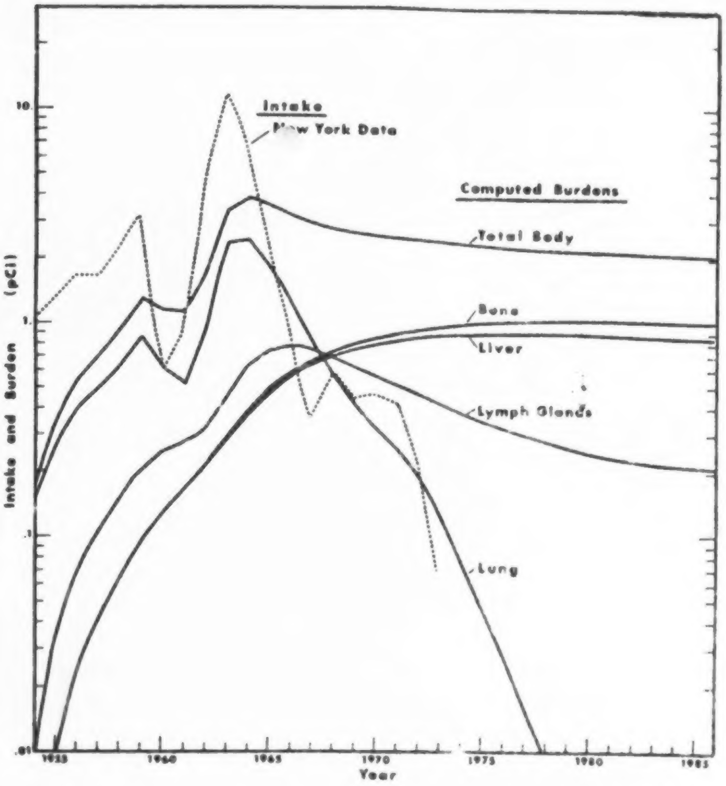


Figure 4-5. Inhalation intake and burden in man of fallout ^{239}Pu *(4.4)*

Foods purchased during 1972 in New York for the ^{90}Sr in diet program, were analyzed for ^{239,240}Pu content. Results are shown in table 4-4. Dietary estimates of plutonium intake were made by HASL and are presented in table 4-5. The estimated annual intake of ^{239,240}Pu during 1972 was estimated to be 1.5 pCi. Thirty percent of the plutonium was attributed to grain products, 20 percent to vegetables, fruit and meat and less than 4 percent to milk and dairy products. Comparison with earlier data to determine changes in amounts of plutonium intake is not easily made due to the scarcity of data; however, from what data are available, it appears that decreases have occurred for the most part.

In addition to the dietary samples, 100 tap water samples of New York City drinking water were analyzed. Based upon the analysis and the assumption that the average man drinks 1.4 liters/day, tap water would add 0.1 pCi to the individual's estimated annual intake of plutonium.-

Based upon an uptake 3×10^{-5} to 10^{-6} for the gastrointestinal tract, the 1.5 pCi intake during 1972 would contribute at most 5×10^{-5} pCi to the body burden or about 1000 times less than the contribution from inhalation intake.

Table 4-4. Fallout ^{239,240}Pu in food, New York - 1972 *(4.5)*

Sample			Concentration	
	Weight (kg)	ash (g)	dpm/sample	pCi/kg (fresh weight)
Shellfish	4.7	100	.12 ± .01	.011
Bakery products	5.3	100	.10 ± .01	.0085
Whole grain products	4.5	100	.06 ± .01	.0060
Fresh fruit	16.9	100	.19 ± .02	.0051
Dry beans	2.8	100	.03 ± .01	.0048
Fresh vegetables	12.6	100	.12 ± .02	.0043
Root vegetables	14.1	100	.11 ± .02	.0035
Poultry	15.0	100	.11 ± .03	.0033
Flour	20.8	100	.13 ± .01	.0028
Meat	10.5	100	.06 ± .02	.0026
Fresh fish	8.6	100	.03 ± .02	.0016
Rice	14.1	80	.05 ± .01	.0016
Potatoes	9.4	100	.03 ± .01 (peeled potatoes)	.0014
Eggs	10.9	100	.03 ± .01	.0012
Macaroni	14.9	100	.04 ± .01	.0012
Canned vegetables	10.2	100	.02 ± .01	.0009
Milk	16.8	120	≤.01	<.0003
Fruit juice	17.5	100	≤.01	<.0003
Canned fruit	27.7	100	≤.01	<.0002

Table 4-5. Fallout $^{239,240}Pu$ dietary intake, New York-1972 *(4.5)*

Item	Consumption (kg/y)	Concentration (pCi/kg)	Intake (pCi/y)
Bakery products	44	.0085	.37
Fresh fruit	59	.0051	.30
Fresh vegetables	48	.0043	.21
Meat	79	.0026	.20
Flour	34	.0028	.095
Whole grain products	11	.0060	.066
Poultry	20	.0033	.066
Milk	200	<.0003	<.06
Potatoes	38	.0014	.053
Root vegetables	10	.0035	.035
Canned vegetables	22	.0009	.019
Eggs	15	.0012	.019
Dry beans	3	.0048	.014
Fresh fish	8	.0016	.013
Shell fish	1	.011	.011
Fruit juice	28	<.0003	<.007
Rice	3	.0016	.005
Macaroni	3	.0012	.004
Canned fruit	11	<.0002	<.002
		TOTAL	1.5 pCi/y

United Nations Scientific Committee on the Effects of Atomic Radiation

Perhaps the best source of dose information derived from many different sources of fallout data, including the HASL data, has been provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The sixth substantive report of UNSCEAR reviews radiation received from all sources to which man is exposed.

Fallout dose information presented by UNSCEAR in the 6th report is currently being updated and should be published in 1977. Although the most recent published report does not contain dose data up to and including the year 1973, it does contain in one single reference the most complete and recent dose information available with some few exceptions such as the HASL plutonium doses discussed previously. Presented below is the dose information contained in the latest UNSCEAR report.

Tritium doses

Based upon an estimated 1900 megacuries of tritium released by nuclear weapons tests up to 1963 *(4.6)* (most of which was in the Northern Hemisphere), the UNSCEAR estimates the dose commitments to be 4 and 1 millirads for the Northern and Southern Hemispheres, respectively *(4.6)*.

Carbon-14

The total estimated ^{14}C inventory from weapons tests has been estimated to be 6.2 megacuries compared to a natural inventory of 280 megacuries. UNSCEAR estimates dose commitments of 140 millirads and 170 millirads to soft tissue and endosteal cells, respectively. Because of the long halflife of ^{14}C, most of the dose commitment occurs over thousands of years; the part of the commitment that will occur up to the year 2000 is estimated to be 12 millirads to the gonads and 14 millirads to the cells lining bone surfaces *(4.6)*.

Iron-55

The total production of ^{55}Fe from tests since 1961-1962 is estimated to be about 50 megacuries. Activity estimates based upon monitoring in North and South America dropped from about 500 fCi/m^3 to a few femtocuries per cubic meter by 1970. Body burdens calculated from different places about the world range from 20-30 nanocuries in 1966 to 1-10 nanocuries in 1969. Assuming a maximum body burden of about 30 nanocuries in the temperate latitudes, dose estimates are 1 millirad to the gonads and bone-lining cells and 0.6 millirads to the bone marrow. For the Southern Hemisphere, doses are estimated to be about 1/4 that of the temperate latitudes *(4.6)*.

Krypton-85

The atmospheric inventory of ^{85}Kr produced by nuclear weapons tests has been estimated to be about 3 megacuries. ^{85}Kr is a beta emitter, however, it also produces a gamma photon in 0.4 percent of the disintegrations. By external irradiation, beta rays deliver a dose to the skin and to subcutaneous tissues, while gamma radiation is responsible for whole body and gonad doses. Internal radiation also occurs from inhalation. The dose to the gonads from external radiation is estimated to be 17 nrad/y per pCi/m^3. The dose commitment to the gonads is estimated to be about 0.2 microrad *(4.6)*.

Radiostrontium

Based upon ^{90}Sr deposition measurements taken worldwide and calculations of uptake by man in diet, the UNSCEAR estimates that the dose commitment from ^{90}Sr from all tests up to 1970 are *(4.6)*:

	Northern Hemisphere		Southern Hemisphere	
	Temperate latitudes (mrad)	Average (mrad)	Temperate latitudes (mrad)	Average (mrad)
Bone marrow	62	45	17	11
Endosteal cells	85	61	23	15

Iodine-131

Iodine-131 fallout deposition patterns are unpredictable throughout the world; hence, the estimation of worldwide doses is not possible unless extensive data on deposition and milk production and consumption throughout the world are known. Because of the limitation of data, UNSCEAR has only provided estimates of ^{131}I doses at some local areas throughout the world, but did not include the United States.

Cesium-137

UNSCEAR estimates that the average integrated deposits of ^{137}Cs in the northern and southern temperate latitudes are 128 and 35 nCi/m^2, respectively. The corresponding dose commitments from diet for these deposits are 26 and 7 millirads. If the dose commitments are calculated on a population-weighted basis over the whole of each hemisphere, the commitments are 19 and 4 millirads for the Northern and Southern Hemispheres, respectively *(4.6)*.

External dose commitments from ^{137}Cs ground deposition have been estimated for the period 1950-1970 to be 134 and 32 millirads for the Northern and Southern Hemispheres, respectively *(4.6)*.

Plutonium

Based upon estimates of the total integrated level of fallout plutonium since the beginning of weapons tests to 1970, the UNSCEAR estimates that the integrated doses over 50 years to be 2, 400, 0.8, and 0.2 millirads to the pulmonary region, the lymph nodes, the liver, and the bone, respectively *(4.6)*.

Short-lived fission products

UNSCEAR, using ^{90}Sr deposition data up to 1967 at Abingdon, United Kingdom, has computed an estimate of the Northern Hemisphere, population-weighted, dose commitment of 144 millirads. Based upon estimates of fallout of ^{90}Sr for 1968-1969, a dose commitment of 4 millirads for 1968-1969 is estimated. Thus, the total population-weighted dose commitment for short-lived fission products for 1961-1969 is estimated as 148 millrads for all deposition in the Northern Hemisphere, and the dose commitment for the northern temperate latitudes is estimated as 203 millirads *(4.6)*.

Based upon ^{90}Sr deposition from 1961-1969 in the Southern Hemisphere to the dose commitment from short-lived products is estimated by UNSCEAR to be 40 millirads. In the southern temperate regions, it is estimated to be 60 millirads *(4.6)*.

Summary - UNSCEAR results

Table 4-6 summarizes UNSCEAR estimates of dose commitments from weapons tests conducted prior to 1971. Table 4-6 also presents estimates given in the UNSCEAR 1969 report for tests conducted prior to 1968. Although no major series of tests were conducted during the period 1968-1970, there are significant differences between the estimates made for internal dose commitments from ^{90}Sr to bone-lining cells and for external dose commitments to all tissues. These changes are mostly due to the availability of improved information *(4.6)*. As a result, the ratios of external to internal estimated dose commitments for all tissues are higher for 1972 than 1969.

Table 4-6. Dose commitments from nuclear tests carried out before 1971. (The dose commitments from nuclear tests carried out before 1968, taken from the 1969 report, are indicated between parentheses) *(4.6)*

	Dose commitments (mrad) for the north temperate zone			Dose commitments (mrad) for the south temperate zone			Dose commitments (mrad) to the world population		
Source of radiation	Gonads	Bone-lining cells	Bone marrow	Gonads	Bone-lining cells	Bone marrow	Gonads	Bone-lining cells	Bone marrow
External									
Short-lived	65 (36)	65 (36)	65 (36)	19 (8)	19 (8)	19 (8)	44	44	44
^{137}Cs	59 (36)	59 (36)	59 (36)	16 (8)	16 (8)	16 (8)	40	40	40
^{85}Kr	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$
Internal									
^{3}H	4	4	4	1	1	1	4	4	4
^{14}C	12 (13)	15 (16)	12 (13)	12 (13)	15 (16)	12 (13)	12	15	12
^{55}Fe	1	1	0.6	0.3	0.3	0.2	0.7	0.7	0.4
^{90}Sr		85 (130)	62 (64)		23 (28)	17 (14)		57	42
^{137}Cs	26 (21)	26 (21)	26 (21)	7 (4)	7 (4)	7 (4)	18	18	18
^{239}Pu[a]		0.2			0.05			0.1	
Total[b]	170 (110)	260 (240)	230 (170)	55 (33)	81 (64)	72 (47)	120	180	160

[a] The dose commitment to bone-lining cells for the north temperate zone has been taken to be equal to the integrated dose over 50 years to bone. A reduction by a factor of four has been assumed for the south temperate zone. Because of insufficient data, the dose commitments to gonads and to bone marrow have not been estimated.

[b] Totals have been rounded off to two significant figures.

Because of the higher dose commitments for external radiation and lower dose commitments from ^{90}Sr, the relative importance of ^{90}Sr has decreased and ^{137}Cs appears to be the main contributor to total dose commitment *(4.6)*.

Predicted doses

A prediction of doses from atmospheric nuclear tests was made in a study published in 1972 *(4.7)*. A summary of these doses is presented in table 4-7.

Summary

UNSCEAR provides population-weighted dose estimates on a world-wide basis usually reported by temperate zone in each hemisphere. The disadvantage to this reporting procedure is that this information is not specific to the United States. However, in a way, the data indicate that the annual cumulative worldwide deposition reached a maximum around 1965, and it has been decreasing ever since as radio-active decay exceeds fallout. Table 4-6 of this chapter summarizes the estimates of dose commitment from the significant fission products of fallout resulting from tests conducted prior to 1971. Although the data are reported on a global basis, they indicate that most of the dose is committed to the population in the Northern Hemisphere and that ^{137}Cs appears to be the most significant contributor to this dose commitment. An estimation of the doses to the U.S. population from fallout was presented in table 4-7. These estimations indicate that the per capita dose will increase slightly during the 1970 to 2000 time period.

Table 4-7. Total annual whole-body doses from global fallout *(4.7)*

Year	U.S. population (millions)	Per capita dose (mrem)	Dose for U.S. population (10^6 person-rem)
1963	190	13	2.4
1965	194	6.9	1.3
1969	204	4.0	0.82
1980	237	4.4	1.1
1990	277	4.6	1.3
2000	321	4.9	1.6

References

(4.1) VOCHOK, H. L. and LAWRENCE TOONKE. Worldwide deposition of ^{90}Sr through 1973. US Atomic Energy Commission Report HASL-286, pp I-17, I-35 (October 1974).

(4.2) BENNETT, B. G. Strontium-90 in the diet - results through 1973 US Atomic Energy Commission Report HASL-284, pp I-34, I-48 (July 1, 1974).

(4.3) BENNETT, B. G. Strontium-90 in human bone - 1973 results for New York City and San Francisco. US Atomic Energy Commission Report HASL-286, pp I-53, I-70 (October 1, 1974).

(4.4) BENNETT, B. G. Fallout ^{239}Pu dose to man. US Atomic Energy Commission Report HASL-278, pp I-41, I-63 (January 1, 1974).

(4.5) BENNETT, B. G. Fallout ^{239,240}Pu in diet. US Atomic Energy Commission Report HASL-286, pp I-36, I-52 (October 1, 1974).

(4.6) UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION. Ionizing Radiation Levels and Effects Volume 1: Levels, United Nations, New York (1972).

(4.7) KLEMENT, A. W. JR., C. P. MILLER, R. P. MINX, and B. SHLEIEN. Estimates of ionizing radiation doses in the United States: 1960-2000, ORP/CSD 72-1. U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C. (August 1972).

Chapter 5 - Uranium Fuel Cycle

Uranium Mining and Milling

Uranium has been milled in the United States since the late 1940's. Ores containing uranium have actually been mined since around 1900 in the Slickrock, Colo., area.

Mining locations in the United States

Uranium ore producing mines have been operated in the States of Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. From 1948 to 1974, 270,100 tons of U_3O_8 have been produced from 116,962,000 tons of ore in the United States, and 65 percent have come from the States of New Mexico and Wyoming, 42 and 23 percent, respectively *(5.1)*. The Colorado plateau area shown in figure 5-1, accounting for 72 percent of the U_3O_8 (produced and known $8 reserves), includes the four corners area of Arizona, Colorado, New Mexico, and Utah. The Wyoming Basins account for 18 percent, and all others, 10 percent of these reserves. The significant uranium areas of the United States are listed in table 5-1.

The number of acres held by the uranium industry for exploration and mining peaked in 1969 and on January 1, 1970, 27,279,000 acres were held. As of January 1, 1974, 18,774,000 acres were held. Forty-six percent of this land was in the State of Wyoming (8,598,000 acres) followed by New Mexico (17 percent), Utah (15 percent), and Colorado (7 percent). The remaining 10 States ranged from Arizona with 754,000 acres (4 percent) to Oregon with 31,000 acres (0.2 percent) *(5.1)*.

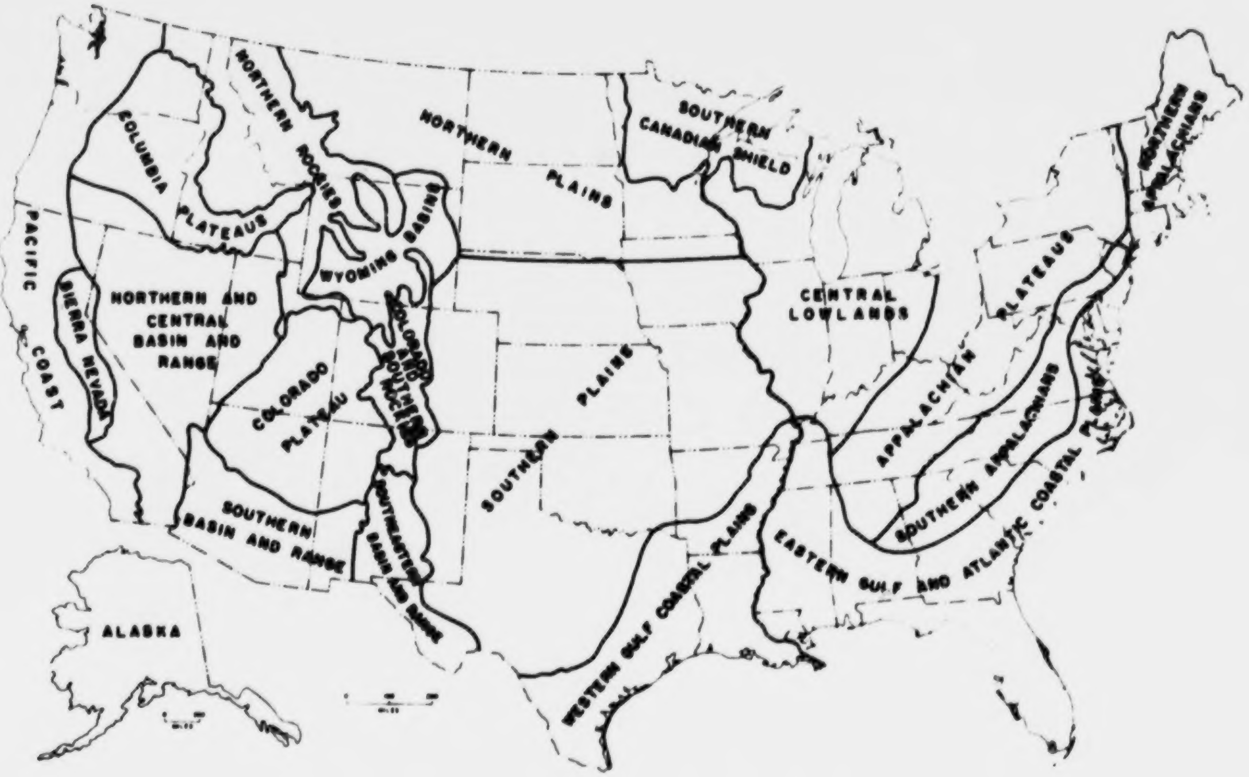

NORTHERN ROCKIES
COLUMBIA PLATEAUS
NORTHERN PLAINS
SOUTHERN CANADIAN SHIELD
NORTHERN APPALACHIANS
PACIFIC COAST
SIERRA NEVADA
NORTHERN AND CENTRAL BASIN AND RANGE
WYOMING BASINS
COLORADO AND SOUTHERN ROCKIES
COLORADO PLATEAU
CENTRAL LOWLANDS
APPALACHIAN PLATEAUS
SOUTHERN PLAINS
SOUTHERN APPALACHIANS
EASTERN GULF AND ATLANTIC COASTAL PLAINS
WESTERN GULF COASTAL PLAINS
SOUTHERN BASIN AND RANGE
SOUTHEASTERN BASIN AND RANGE
ALASKA

Figure 5-1. Geological resource regions of the United States *(5.1)*

Types of mining

Two types of mining are practiced in the United States, strip or pit mining and underground mining. Strip mining produces the largest amount of waste because of stripping the overburden from above the ore horizon. For instance, in Wyoming during 1974, 2,666,000 tons of uranium ore were mined. The wastes produced were 103,531,000 tons of overburden, 515,000 tons of waste rock, and 2,984,000 tons of mill tailings. Colorado mined 1,216,000 tons of ore and produced 1,210,000 tons of tailings *(5.2)*. All of Colorado's production was from underground mines while almost all of Wyoming's production comes from strip mines; thus, strip mining produces vast quantities of waste.

Table 5-1. Significant uranium areas of the United States *(5.1)*

State	Area	U_3O_8 production and reserves	
		> 500 tons	< 500 tons > 10 tons
Alaska	Prince of Wales Island	X	
Arizona	Cameron	X	
	Grand Canyon	X	
	Globe		X
	Monument Valley	X	
	Tuba City		X
	West Central		X
California	East Central		X
	Southeast		X
Colorado	Front Range	X	
	Gunnison		X
	Marshall Pass	X	
	Maybell	X	
	Rifle		X
	Uravan Mineral Belt	X	
Idaho	Lowman		X
Montana	South Central Border		X
Nevada	Austin		X
	North Central		X
New Mexico	Grants Mineral Belt	X	
	Laguna		X
	Shiprock	X	
North Dakota	Belfield		X
Oregon	Lakeview		X
South Dakota	Cave Hills	X	
	Edgemont	X	
	Slim Buttes	X	
Texas	Falls City	X	
	Ray Point	X	

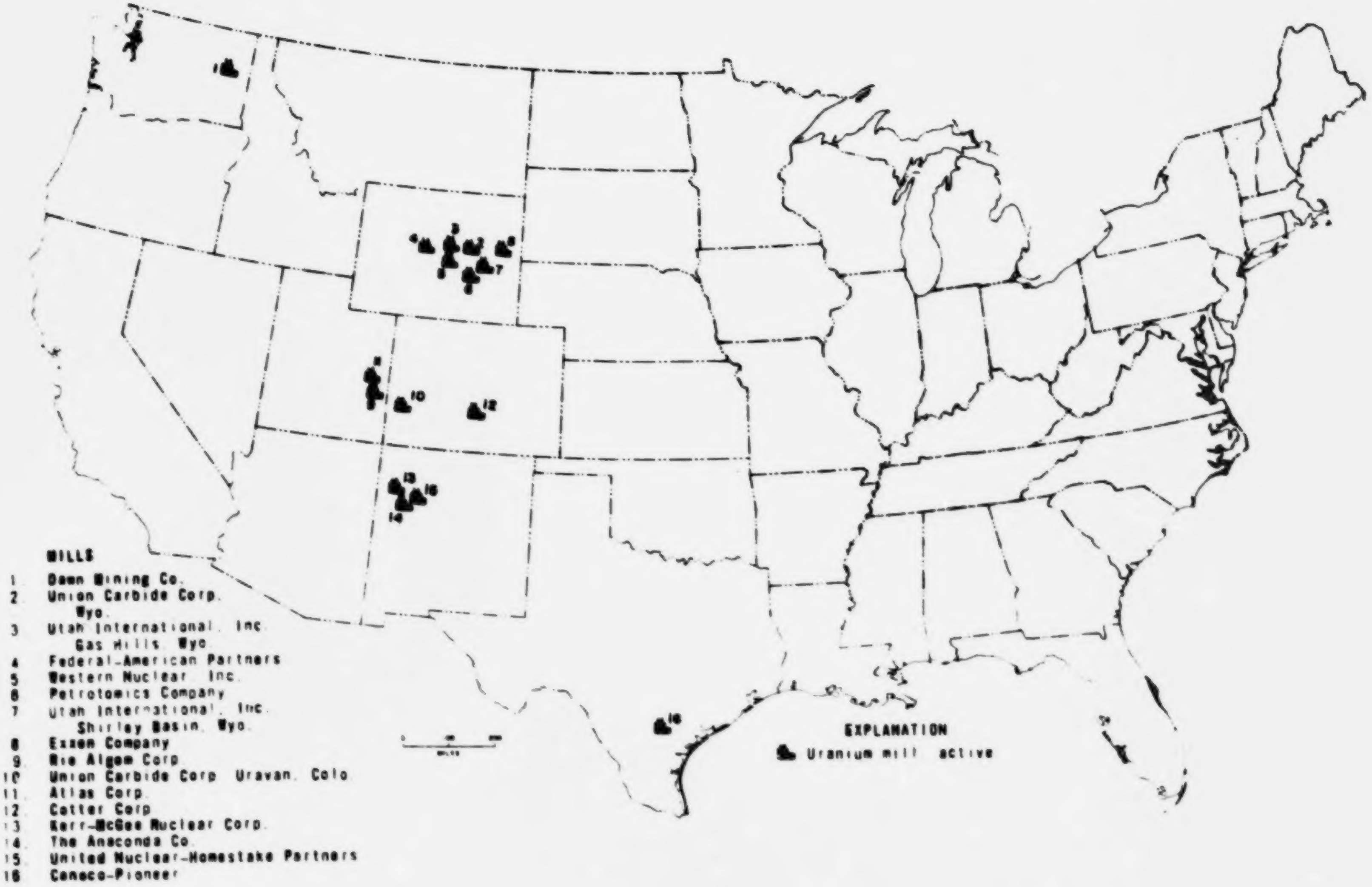
Table 5-1. Significant uranium areas of the United States cont.

State	Area	U_3O_8 production and reserves > 500 tons	< 500 tons > 10 tons
Utah	Canyon Lands		X
	Green River	X	
	Inter River (Moab)	X	
	Lisbon Valley	X	
	Marysvale	X	
	Mexican Hat		X
	San Rafael	X	
	Thompson		X
	White Canyon	X	
Washington	Spokane (Ford)	X	
	North of Spokane		X
Wyoming	Black Hills	X	
	Crooks Cap	X	
	Gas Hills	X	
	Powder River Basin	X	
	Shirley Basin	X	

Active uranium mills

The uranium mills that were in operation in the United States as of January 1, 1974, are shown in figure 5-2 and listed in table 5-2. Ninety-one percent of the stated nominal milling capacity was centered in the States of New Mexico (50 percent), Wyoming (28 percent), Colorado (7 percent), and Utah (6 percent). The remaining 9 percent was in the States of Texas (7 percent) and Washington (2 percent). Figures 5-3 to 5-6 show the trends that have been developing in the uranium mining and milling industry since 1965.

Strip mining probably produces more problems for the environment than underground mining. While underground mining does not produce as great a volume of waste, it produces greater hazards for the miners. Rock falls and equipment accidents are constantly present but another hazard is the exposure to the radon daughters produced from radon.


MILLS
1. Dawn Mining Co.
2. Union Carbide Corp., Wyo.
3. Utah International, Inc., Gas Hills, Wyo.
4. Federal-American Partners
5. Western Nuclear, Inc.
6. Petrotomics Company
7. Utah International, Inc., Shirley Basin, Wyo.
8. Exxon Company
9. Rio Algom Corp.
10. Union Carbide Corp., Uravan, Colo.
11. Atlas Corp.
12. Cotter Corp.
13. Kerr-McGee Nuclear Corp.
14. The Anaconda Co.
15. United Nuclear-Homestake Partners
16. Conoco-Pioneer
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EXPLANATION
Uranium mill, active
MILES

Figure 5-2. Active uranium ore processing mills *(5.1)*

Table 5-2. U.S. uranium mills as of January 1, 1974 *(5.1)*

Company	Location	Nominal capacity (tons ore per day)
Anaconda Company	Bluewater, New Mexico	3,000
Atlas Corporation	Moab, Utah	1,000
Conoco & Pioneer Nuclear, Inc.	Falls City, Texas	1,750
Cotter Corporation	Canon City, Colorado	450
Dawn Mining Company	Ford, Washington	400
Federal-American Partners	Gas Hills, Wyoming	950
Exxon Company	Powder River Basin, Wyoming	2,000
Kerr-McGee Nuclear Corporation	Ambrosia Lake, New Mexico	7,000
Rio Algom Corporation	La Sal, Utah	700
Union Carbide Corporation	Uravan, Colorado	1,300
Union Carbide Corporation	Natrona County, Wyoming	1,000
United Nuclear-Homestake Ptns.	Grants, New Mexico	3,500
Utah International, Inc.	Gas Hills, Wyoming	1,200
Utah International, Inc.	Shirley Basin, Wyoming	1,200
Western Nuclear, Inc.	Jeffrey City, Wyoming	1,200
	Total	26,650

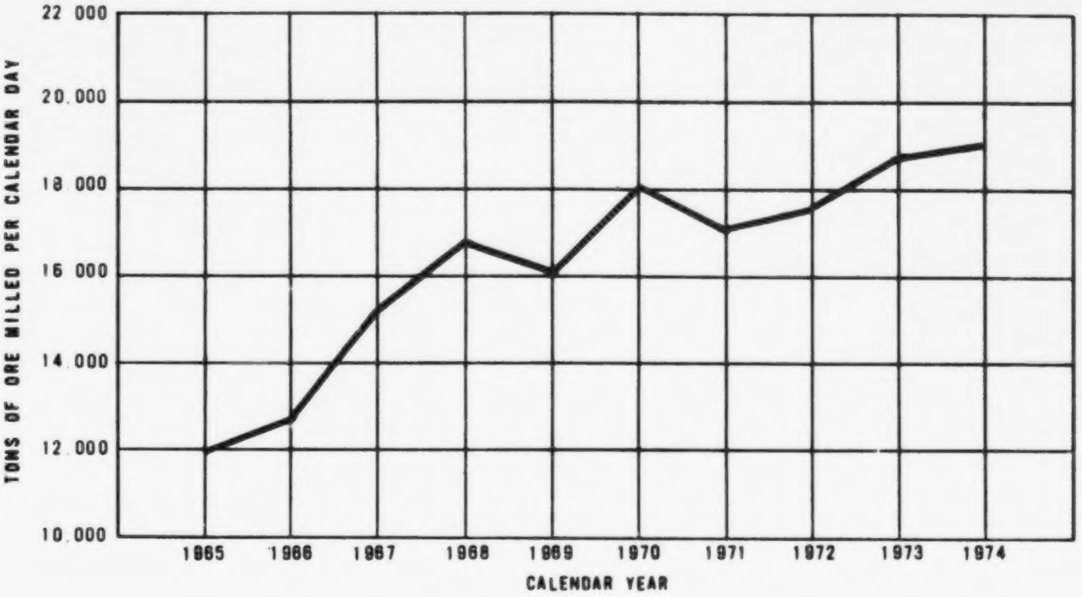

Figure 5-3. Uranium ore processing rates *(5.1)*

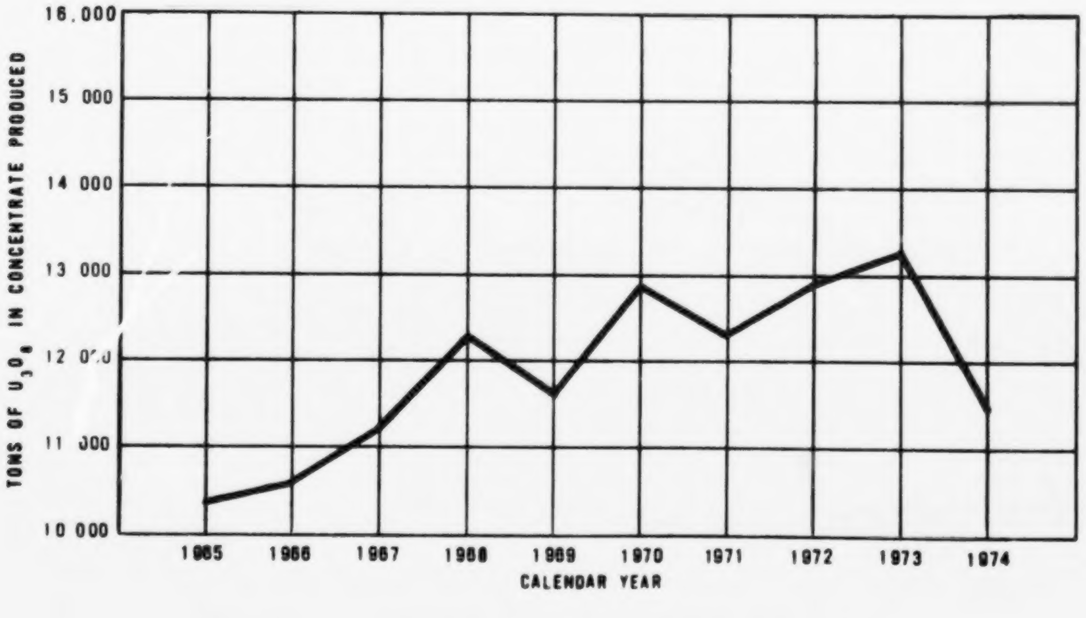

Figure 5-4. Uranium concentrate production *(5.1)*
(includes production from millfeed other than ore)

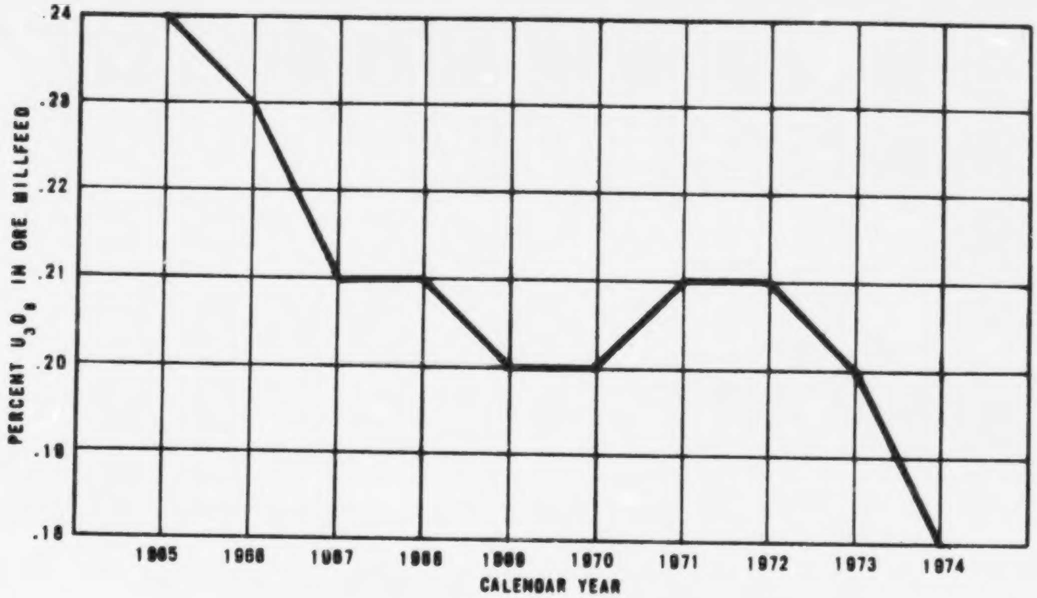

Figure 5-5. Grade of uranium ore processed *(5.1)*

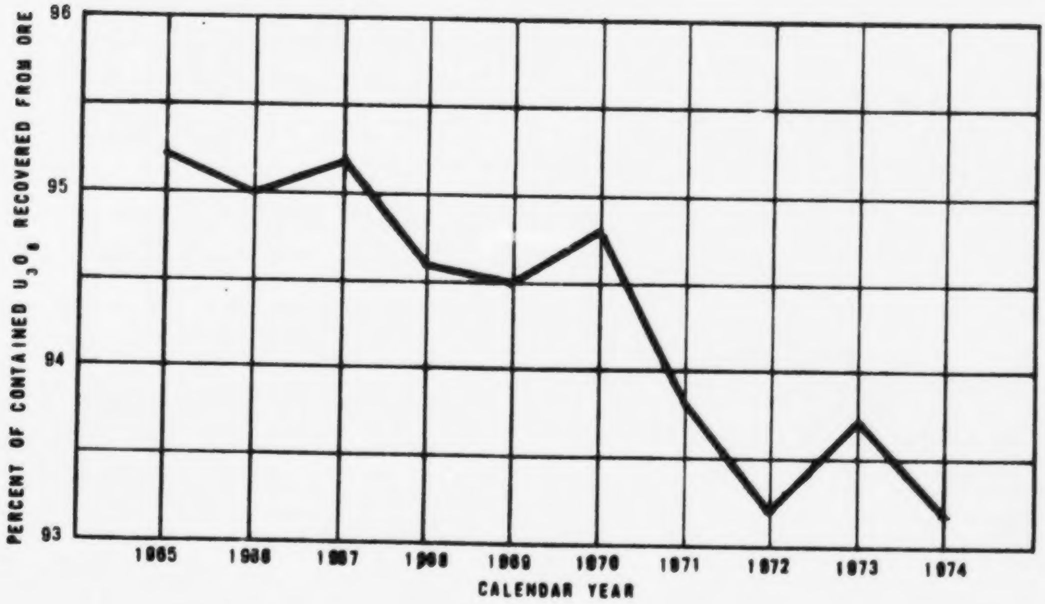

Figure 5-6. Recovery from ore processed *(5.1)*

Dose data

Although the doses to individuals or populations in the vicinity of uranium mills has been nonexistent, doses have been predicted for a model uranium mill *(5.3)*. The dose estimates from routine effluents of a model mill to individuals in the vicinity of the mill through the air pathway are given in table 5-3. The estimated doses to the population in the vicinity of the mill are given in table 5-4.

Fuel Enrichment

There are three government-owned gaseous diffusion plants operated in the United States. These plants are located at Oak Ridge, Tenn., Paducah, Ky., and Portsmouth, Ohio. The gaseous diffusion technology is used to enrich uranium-235 content from about 0.7 percent to 2 to 4 percent for use in light water reactors and up to about 90 percent enrichment for use in high temperature gas-cooled reactors.

The contractors who operate these plants conduct environmental monitoring about their plants to determine the impact of their operations upon the environment and man. The results of the monitoring activities are published yearly. The 1973 results which are summarized below were published in references *5.4-5.6*.

Oak Ridge

There are three major facilities at Oak Ridge. They are the Oak Ridge National Laboratory (ORNL), the Oak Ridge Gaseous Diffusion Plant, and the Y-12 plant. Radioactive waste and effluents are generated at these facilities. The monitoring data available for the the Oak Ridge Facility as reported in reference *5.4* does not differentiate environmental concentrations and doses from these facilities; hence, only the total environmental impact for Oak Ridge is available. Thus, any contribution by the gaseous diffusion plant would be less than or, at the worst, equal to the total contribution of radioactivity to the environment and man by the whole Oak Ridge Facility.

Doses at Oak Ridge, based upon contributions for all activities at Oak Ridge, were estimated to be:

a. Maximum potential dose to an Oak Ridge resident was 0.17 mrem/y to the whole body and 4.8 mrem/y to the lung.

b. Average exposure to an Oak Ridge resident was estimated to be 0.1 mrem/y.

c. The cumulative whole body dose to the general population within a 40-mile radius of Oak Ridge which resulted from plant effluents was about 14 person-rem in 1973.

Table 5-3. Radiation doses to individuals due to inhalation in the vicinity of a model mill *(5.3)*

Radionuclide	Source term (mCi/y)	Critical organ	Dose equivalent to critical organ	
			Individual at plant boundary (mrem/y)	Average individual within 80 km (mrem/y)
Uranium-234 and 238	180	Lung	170	3.9×10^{-2}
Thorium-230	15	Lung	15	3.4×10^{-3}
Radium-226	10	Lung	15	2.2×10^{-3}
Total	205		200	4.5×10^{-2}

Table 5-4. Collective dose to the general population in the vicinity of a model mill *(5.3)*

Radionuclide	Source term[a] (mCi/y)	Pathway	Critical organ	Collective critical organ dose (person-rem/y)
Uranium-234 and 238	180	Air	Lung	2.2
Thorium-230	15	Air	Lung	0.2
Radium-226	10	Air	Lung	0.1
			Total	2.5

[a] Releases to water pathways assumed equal to zero, and doses from radon-222 are not included.

Paducah gaseous diffusion plant

An extensive monitoring program is routinely conducted about the Paducah plant from which environmental concentrations are determined and doses are calculated. The dose estimates for 1973 are summarized below.

a. Maximum "fence post dose". Based upon measured alpha activity in ambient air, the maximum fence post dose was estimated to be about 36 mrem/y to the lung. Calculations of the lung dose based upon uranium effluents and prevailing meteorological conditions at the location of the maximum measured activity yield a dose of less than 3 mrem/y.

b. The potential lung dose to a family living nearest to the plant was estimated to be about 15 mrem/y based upon continuous occupancy or about 8 mrem/y for a resident who is away from the home about 8 hours per day.

c. The potential lung dose to a member of the nearest community was estimated to be about 5 mrem/y assuming continuous residence.

Portsmouth gaseous diffusion plant

At the Portsmouth gaseous diffusion plant, the ambient atmosphere and all effluent streams are sampled and analyzed regularly. Based upon these analyses, the maximum annual radioactivity dose (lung burden) was calculated for various points along the plant perimeter and for Piketown, the nearest population center (calculations were based upon Pasquill dispersion coefficients for stability class "D"). The maximum lung dose at the plant boundary was calculated to be 6 mrem/y. The maximum dose at Piketown was estimated to be 0.53 mrem/y.

Predicted doses

In a generic study of the uranium fuel cycle *(5.7)*, dose estimates based upon an assumed "model" facility for a gaseous diffusion plant were made. These estimates were made considering the bone as the critical organ and were quite small being about 3×10^{-4} mrem/y per facility-year of operation for individuals within 80 km of the facility due to inhalation and about 0.07 mrem/y per facility-year to bone from drinking water.

Summary

Despite the source or method of calculating doses from enrichment facilities it is concluded that, based upon available data, the doses are small.

Fuel Fabrication Plants

There is relatively little data available in the literature concerning the release of radioactivity from fuel fabrication plants and the resulting exposures and doses to the general population.

A single study *(5.7)* by the U.S. Environmental Protection Agency was made in 1973 to analyze and project what effects the total uranium fuel cycle may have upon the public health. Because of the lack of specific detailed data, the analysis was performed using model plants which typified those in existence for the various functions in the fuel cycle such as milling, conversion, enrichment, and fabrication. This study presents the best estimates of dose available which result from fuel fabrication activity.

Based upon an assumed release of 0.005 Ci/y of uranium, the maximum dose to an individual at the plant boundary from the inhalation pathway would be 10 mrem/y per facility-year to the lung, and 0.002 mrem/y per facility-year to an individual within 80 km of the model facility. Corresponding individual doses from the water pathway (drinking water) were 0.6 and 0.06 mrem/y per facility-year to the bone for an individual at the plant boundary and an average individual within 300 km of the plant, respectively. The corresponding doses to soft tissue from drinking water are 0.06 and 0.006 mrem/y per facility-year. The aggregate population doses for the general population within 80 km of a model facility were estimated to be 3 person-rem/y per facility-year to the lung via the air pathway, 34 person-rem/y per facility-year to the bone from the water pathway, and 3 person-rem/y per facility-year to soft tissue from the water pathway.

Summary

For the 10 fuel fabrication plants in the United States, very little data concerning effluents, environmental monitoring, and population dose and exposure exist within the literature. Because of the scarcity of data, only very rough estimates of dose from these facilities can be made. Unless more specific data is developed concerning fuel fabrication facilities, no specific information concerning their impact upon the environment can be developed.

The estimated plant boundary, average individual and aggregate population doses expected from the operation of a fuel fabrication facility are shown in table 5-5.

Power Reactors

In 1973 there were 40 civilian nuclear power reactors operating in 18 States in the United States. Radiation from these reactors reaches the environment either as direct radiation from the reactor, which may be of significance only near the reactor boundary, or through discharges of low level, radioactive, gaseous and liquid wastes from reactor operations.

Monitoring of the reactor environment is performed in order to determine the impact of nuclear power reactors on the environment.

Description of data base

By the enactment of the National Environmental Policy Act of 1969, the Nuclear Regulatory Commission (NRC) [Atomic Energy Commission (AEC) in 1973] is required to prepare an Environmental Impact Statement for each nuclear power plant. These statements contain data on baseline

Table 5-5. Estimated doses from fuel fabrication facility operations

Dose	Inhalation Lung	Drinking water Bone	Drinking water Soft tissue
Maximum dose to individual at plant boundary (mrem/y)	10	0.6	0.06
Average individual dose (mrem/y)	[a]0.002	[b]0.06	[b]0.006
Aggregate population dose (person-rem/y)	[a]3	[a]34	[a]3

[a]Within 80 km of facility

[b]Within 300 km of facility

levels of radioactivity in the environment and predicted radiation doses to the public from normal plant operations. After an operating license is granted, the licensee is required, under Title 10, Part 50 of the Code of Federal Regulations *(5.8)*, to file an operating report semi-annually *(5.9)*. An environmental monitoring report may be filed as part of the licensee's operating report or as a separate report. These reports are available to the public at NRC public document rooms.

Collection of data for the reports is often carried out by a contracting firm specializing in environmental radiation surveys. The information required in environmental monitoring reports varies somewhat according to the technical specifications in the license for each nuclear reactor. However, the data generally include gross alpha, gross beta, and gamma-emitting radionuclide, ^{90}Sr, ^{89}Sr, and ^{3}H concentrations in samples of air, air particulates, surface water, ground water, drinking water, sediment, milk, and other food products which are locally available. External dose measurements are usually made using thermoluminescent dosimeters at various locations around the reactor.

Individual States have environmental surveillance programs around nuclear power reactors, usually carried out by a division of the State Board of Health or Environmental Protection Agency. The State programs vary in monitoring capabilities; States having several nuclear facilities have extensive programs. A report summarizing State environmental radioactivity surveillance programs contains information on sample media, sites, collection and analysis frequency, and types of analysis performed for each state *(5.10)*. A directory published by the U.S. Environmental Protection Agency (EPA) *(5.11)* has a section giving a brief description of the environmental monitoring program for each State and includes the name of the person to contact for more information.

As a help to firms or agencies conducting surveillance programs, the EPA Office of Radiation Programs has published a guide *(5.12)* recommending specific methods for a minimum level of environmental radiation surveillance. The Atomic Industrial Forum, in a two volume book compiled by Battelle Laboratories *(5.13)*, provides a broader base for types of monitoring methods, including ecological as well as radiological monitoring methods.

The reports, mentioned above, prepared by the operators of nuclear power plants and by the appropriate State agencies, are the only routine source of primary environmental radiation data. However, in 1973 some special field studies were carried out by government agencies, such as the EPA, the AEC, and individual States.

A joint field study by EPA and AEC *(5.14)* was conducted during 1973 to measure iodine-131 in environmental samples of air, rainfall, vegetation, and milk collected around the Dresden, Monticello, and Oyster Creek nuclear power plants. Data from the field study was compared with levels of radioactivity in samples that were predicted by mathematical models in order to determine their validity.

A comprehensive radiological surveillance study at the Haddam Neck nuclear power station *(5.15)* by EPA measured radionuclide concentrations in the environment and external radiation doses around the pressurized water reactor (PWR) facility. This study follows similar studies at the Dresden boiling water reactor (BWR) *(5.16)*, and Yankee-Rowe PWR *(5.17)*. Another study by EPA at the Shippingport Atomic Power Station *(5.18)* measured iodine-131 and strontium-90 concentrations in milk and soil samples, and ambient radiation levels using thermoluminescent dosimeters.

Dose data

Some power reactor operators report dose information at or outside the site boundary in their semiannual reports to NRC. However, most of these reports lack dose information. Dose measurements at Haddam Neck during 1971 *(5.15)* resulted in an estimation that an adult at the nearest residence received 0.5 mrem/y from airborne effluents. The maximum potential dose from eating fish caught in the vicinity of the reactor was estimated to be 0.13 mrem/y - whole body and 0.25 mrem/y to the bone. The dose at ground level 0.6 km from the vent was estimated to be 0.2 mrem/y.

Population dose from exposure to operating BWR's for 1973 was calculated by EPA using a computer code and based on gaseous reactor effluent data reported to the AEC *(5.19)*. This resulted in an estimation of a total population dose of 1550 person-rem to populations within 80 km (50 miles) of BWR's.

The New York State Department of Health in a report by J. M. Matuszek, et al. *(5.20)* measured gaseous effluents from one BWR, two PWR's and one high temperature gas-cooled reactor (HTGR). From these data, they estimated doses at 1 km from a theoretical 2500 MW(t) reactor for each reactor type:

	Dose (mrad/y)		
	^{3}H	^{14}C	^{37}Ar
BWR	4×10^{-3}	6×10^{-2}	4×10^{-3}
PWR	2×10^{-3}	$>4 \times 10^{-1}$	1×10^{-2}
HTGR	1.2×10^{2}	<1	1.4×10^{2}

Other reports, while not presenting data for 1973, discuss dose commitment to populations from discharge of carbon-14 and krypton-85 *(5.21)* and from the nuclear power industry in the United States *(5.22, 5.23)*.

As mentioned previously, environmental impact statements (EIS) compiled by the NRC contain estimates of predicted radiation doses to the public from normal operation of nuclear power reactors. These estimates are summarized in a report by the Office of Radiation Programs of EPA *(5.24)*. Table 5-6 lists the calculated maximum doses at the site boundary based on discharges of gaseous effluents for the years 1972 and 1973 and the maximum whole body doses as estimated in the EIS's. The large differences between the predicted dose values and the dose values calculated from actual discharge information may be due to differences in the assumptions used in the calculations. It may be seen in comparing these doses that the calculated doses for BWR's are generally higher than the predicted doses given in the environmental impact statements. The reason for these differences is still being investigated.

Observations

In comparing environmental monitoring data from nuclear power plant licensee's reports to NRC, it is apparent that a more uniform method of acquiring and reporting the data would be desirable. Environmental dose

Table 5-6. Calculated and predicted doses from noble gas releases at operating plants (1972-73) *(5.24)*

Facility (Site)	Start up	Net site capacity [GW(e)]	Annual output (% of capacity)		Fence dose (mrem/y)		Predicted exposure Gaseous (Whole body) (mrem/y)
			1972	1973	1972	1973	
PWR's							
Yankee Rowe	8/60	0.18	40	68	<1	<1	N.A.
Indian Point 1 & 2	8/62,5/73	1.14	16	24	<1	<1	[a]2
San Onofre 1	6/67	0.43	74	60	<1	<1	[a]<1
Haddam Neck	7/67	0.58	85	46	<1	<1	<1
R. E. Ginna	11/69	0.47	57	87	<1	<1	<1
Point Beach 1 & 2	11/70,5/72	0.99	70	67	<1	<1	1
H. B. Robinson	9/70	0.70	72	82	<1	<1	<1
Palisades	5/71	0.70	32	41	<1	<1	<1
Surry 1 & 2	7/72,3/73	1.58	6	65	<1	<1	<1
Turkey Point 3 & 4	10/72,6/73	1.39	-	62	-	<1	<1
Maine Yankee	10/72	0.79	7	58	<1	<1	<1
Oconee 1	4/73	0.88	-	47	-	<1	[a]1
Zion 1	6/73	1.05	-	22	-	<1	[b]1
Fort Calhoun	8/73	0.46	-	42	-	<1	<1
BWR's							
Dresden 1	10/59	0.20	65	33	13	12	[c]<1
Big Rock Point	9/62	0.08	57	68	5	5	N.A.
Humbolt Bay	2/63	0.07	62	77	67	54	N.A.
LaCrosse	7/67	0.05	60	46	<1	3	N.A.
Oyster Creek	5/69	0.64	78	64	37	35	<1

Table 5-6. Calculated and predicted doses from gas releases at operating plants (1972-73) *(5.24)* continued

Facility (Site)	Start up	Net site capacity [GW(e)]	Annual output (% of capacity)		Fence dose (mrem/y)		Predicted exposure Gaseous (Whole body) (mrem/y)
			1972	1973	1972	1973	
BWR's continued							
Nine Mile Point	9/69	0.63	59	68	11	21	[d]<1
Dresden 2 & 3	1/70,1/71	1.62	57	64	2	6	[c]<1
Millstone 1	10/70	0.65	55	34	8	1	[e]<1
Monticello	12/70	0.55	75	68	30	33	1
Quad Cities 1 & 2	10/71,4/72	1.60	28	73	1	7	4
Vermont Yankee	3/72	0.51	10	44	3	16	<1
Pilgrim 1	6/72	0.66	15	71	1	3	[f]<1

[a] Predicted values are for three units.

[b] Predicted values are for two units.

[c] The dose of 22 mrem/y in table 5.3 of the EIS for unit one will be reduced by a factor of 100 by a scheduled augment committed by the applicant (see page 11-40 of the EIS).

[d] Includes the contribution from Fitzpatrick. The site gamma dose assumes 100 hours in a boat at point of nearest approach per year. The figures shown are after scheduled 1975 augment of unit one gaseous effluent control.

[e] One BWR and two PWR units.

[f] One BWR and one PWR units.

N.A. - Not available.

information is not routinely reported. The NRC publishes, annually, a summary of releases of radioactive material to the environment from nuclear power reactors *(5.25)*. If this information included a summary of the releases of individual radionuclides, it would be very helpful in calculating doses to the public.

Summary

Power reactors contribute to environmental radioactivity either as direct radiation from the reactor which is generally significant within the reactor boundary or through discharges of radioactive gaseous and liquid wastes resulting from reactor operations. The total population dose from the gaseous effluents of BWR's for 1973 has been estimated to be 1550 person-rem within a radius of 80 kilometers from the plant. The population dose from PWR's would be expected to be significantly lower, possibly by a factor of 10-50, because of the large reduction in the release of radioactive gaseous effluents.

Research Reactors

In 1973, there were 68 research and test reactors of all types exclusive of those owned by the Energy Research and Development Agency (see chapter 6 for discussion of ERDA facilities). Of these, 1 was a irradiation test reactor; 3 were high power research and test reactors; 13 were general research reactors, and 51 were classified as university research and testing reactors *(5.26)*. The rated power output of the reactors ranged from near 0 to 50,000 kW(t).

Research reactors are regulated by the Nuclear Regulatory Commission *(5.8)*, and the licensees are required to submit annual environmental monitoring reports. These reports are usually included in the reactor operating report and amount to a short paragraph stating the general condition of the environmental monitoring program. The reports are available to the public at the NRC public document room in the regional office nearest the reactor. The most detailed description of the monitoring program for a research reactor can be found in its Final Safety Analysis Report which is filed with the NRC. Typical surveillance programs include gross beta measurements of water and air samples, and direct gamma dose measurements using thermoluminescent dosimeters.

In addition to the surveillance performed by the licensees, the States in which the reactors are situated maintain environmental monitoring programs in the vicinity of each site *(5.10, 5.11)*. Because of the diversity of types and the variation of power output of these reactors, the surveillance that the States perform at the sites varies widely.

There is little or no published information on dose to the public or special surveillance studies carried out by government agencies.

Authority

The two agencies having overlapping regulatory authority for the transportation of radioactive materials are the Department of Transportation (DOT) and the Atomic Energy Commission (AEC), now called the Nuclear Regulatory Commission.

DOT has the authority to regulate the transportation of explosives and other dangerous materials including radioactive materials under the Transportation of Explosives Act (18 USC 831-835), the Dangerous Cargo Act (RS 4472 - as amended, 46 USC 170), and title VI and 902(h) of the Federal Aviation Act of 1958 (49 USC 1421-1430 and 1472(h)) *(5.27)*. This responsibility extends to all modes of transport in interstate or foreign commerce (railroad, air, road, water) and by all means of transport except postal shipments. Postal shipments are under the jurisdiction of the U.S. Postal Service. Shipments not in interstate or foreign commerce are subject to control by a State agency in most cases *(5.28)*.

The AEC under the Atomic Energy Act of 1954, as amended, is authorized to license and regulate the receipt, possession, use, and transfer of byproduct, source, and special nuclear material. A license is required from the AEC for the possession and use of such materials except for certain small quantities and specific products for which the possession and use are exempted. Many States have entered into formal agreements with the AEC whereby the regulatory authority over byproduct, source and less-than-critical quantities of special nuclear material has been transferred to the States from AEC. Most of the States have adopted uniform regulations pertaining to intrastate transportation of radioactive materials which require the shipper to conform to the packaging, labeling, and marking requirements of the DOT to the same extent as if the transportation were subject to the rules and regulations of that agency.

A Memorandum of Understanding, defining the roles of DOT and AEC in the regulation of transportation of radioactive materials, was signed on March 22, 1973 *(5.27)*. This Memorandum states that DOT will adopt regulations imposing standards developed by AEC and DOT on shippers and carriers subject to DOT jurisdiction and will adopt a requirement for AEC approval of packages for shipment of fissile material and Type B and large quantities of material by people not subject to 10 CFR Part 71 or AEC-Manual requirements but subject to DOT jurisdiction. Each agency will conduct an inspection and enforcement program within its jurisdiction to assure compliance with regulations. DOT requires notification and reporting of accidents, incidents, or suspected leakage involving radioactive material packages if such occurs or is discovered while in transit. AEC requires notification and reporting of accidents, incidents or suspected leakage occurring prior to delivery to a carrier for transport or after delivery to a receiver. DOT and AEC agreed in the Memorandum to make available to each other summaries of inspection records, investigations of serious accidents, and other matters relating to safety. The Memorandum of Understanding did not affect the statutory exemption of shipments of radioactive materials made by or under the direction or supervision of the AEC or Department of Defense (DOD) in accordance with the provisions of 18 USC 832(c).

On January 3, 1975, the Transportation Safety Act of 1974 (PL 93-633), was enacted to regulate commerce by improving the protections afforded the public against risks connected with the transportation of hazardous materials, and for other purposes *(5.29)*.

Transportation of radioactive materials in the nuclear power industry

Holmes and Narver, Inc., under a contract with EPA, estimated that the total annual population dose expected in the United States from routine transportation of radioactive materials for the nuclear power industry is a very small fraction of the total annual population doses expected from other sources, such as natural cosmic radiation from outer space, natural radiation from radioactive isotopes in the earth's crust, global fallout from weapons tests, diagnostic x-ray machines, use of radiopharmaceuticals, operating nuclear power plants, and miscellaneous sources including TV sets, microwave ovens, transmission lines, etc. The total annual population dose from transportation of radioactive materials in the country varies from about 140 person-rem/y in 1975 to about 15,000 person-rem/y in 2020 *(5.30)*.

The report states further that the greatest radiation dose from routine transportation of nuclear facility-related materials is projected to come from transportation of low level waste from reactors to commercial burial grounds. Because of the large number of shipments and the long shipping distances involved, the annual population dose is projected to vary from about 100 person-rems/y in 1975 to about 8,000 person-rems/y in 2020. These doses are about 4 or 5 times as large as the corresponding doses from spent fuel shipments even though the low level waste shipments are assumed to be only one-fourth as radioactive as spent fuel shipments.

Table 5-7 gives a summary projection of annual national population radiation dose from routine transportation of materials in the nuclear power industry. Table 5-8 presents projected estimates of annual population dose from transportation.

In another study for EPA, Holmes and Narver, Inc., made a quantitative assessment of the accident risks associated with the transportation of radioactive materials in the nuclear power industry for the period 1975-2020 *(5.31)*. The radioactive materials considered in the report were spent fuel, plutonium, high-level radioactive solid waste, and fission product gases. The consequences of accidents evaluated were radioactivity released and population doses. Methods of transportation

Table 5-7. Summary projection of annual national population radiation dose from routine transportation of materials in the nuclear power industry *(5.30)*

		Material					
				Radioactive solid waste			
Year	Parameter	Spent fuel	Recycled plutonium	High level	Intermediate level[b]	Low level[c]	Total[d]
1980	Amount transported	2,400 MT	40 MT	-	-	31,000m^3	-
	Expected shipments	1,080	310	-	-	14,600	16,000
	Shipping distance (km)[a]	8,470	3,990	18,870	18,870	7,900	-
	Shipping units (10^6 shipment-km)	0.47	0.03	-	-	7.74	8.74
	Population density (people/km^2)	29.7	29.7	29.7	29.7	29.7	29.7
	Population dose (person-rems)	74	9	-	-	290	370
2000	Amount transported	17,600 MT	680 MT	550m^3	970m^3	260,000m^3	-
	Expected shipments	7,800	5,100	350	310	115,000	130,000
	Shipping distance (km)	4,350	3,990	18,870	18,870	5,000	-
	Shipping units (10^6 shipment-km)	1.90	0.86	0.76	0.69	43.97	48.18
	Population density (people/km^2)	37.0	37.0	37.0	37.0	37.0	37.0
	Population dose (person-rems)	490	210	280	260	2,300	3,500
2020	Amount transported	35,200 MT	3,060 MT	2,200m^3	5,950m^3	736,000m^3	-
	Expected shipments	15,610	23,270	1,400	2,000	249,000	290,000
	Shipping distance (km)	4,570	3,990	18,870	18,870	5,400	-
	Shipping units (10^6 shipment-km)	4.26	4.88	2.76	5.43	119.72	137.05
	Population density (people/km^2)	46.3	46.3	46.3	46.3	46.3	46.3
	Population dose (person-rems)	1,400	1,300	1,200	2,300	8,600	15,000

[a] Sum of average distances in the six Federal Power Commission Regions.

[b] Includes only waste transported from chemical processing plants to the Federal Waste Repository.

[c] Includes both waste transported from chemical processing plants to commercial burial grounds and waste transported from reactors to commercial burial grounds.

[d] Numbers may not add exactly because of rounding.

Table 5-8. Projected estimates of annual population dose from transportation *(5.30)*

Source	Estimated annual population dose in United States[a] (10^6 person-rem/y)				
	1960	1970	1980	1990	2000
Transportation of:					
Spent fuel	--	--	7.4×10^{-5}	2.4×10^{-4}	4.9×10^{-4}
Recycled plutonium	--	--	9.0×10^{-6}	1.4×10^{-5}	2.1×10^{-4}
High level waste	--	--	--	7.8×10^{-5}	2.8×10^{-4}
Intermediate level waste	--	--	--	7.9×10^{-5}	2.6×10^{-4}
Low level waste	--	--	2.9×10^{-4}	9.1×10^{-4}	2.3×10^{-3}
Total	--	--	3.7×10^{-4}	1.1×10^{-3}	3.6×10^{-3}

[a] Annual whole body dose to the entire population within the continental United States.

considered were truck, rail, and barge. The study determined that the public health risks from the release of radioactivity from transportation accidents in the industry is relatively small because of the low probability of accidents, the small fraction of the accidents resulting in the release of radioactivity, and because the majority of releases are relatively small fractions of the radioactive contents. Nevertheless, the amount of radioactivity accidentally released is sufficient to raise issues of public concern. The report also states there are very little statistical data on which to assess the risk of release of radioactivity from the shipment package as a result of an accident during transportation. Within the United States over the past 25 years, there have been about 300 reported accidents in transportation involving packages of all kinds of radioactive material. About 30 percent of those accidents involved release of radioactive material from medical and industrial radiochemicals. The report states that none of these accidents resulted in perceptible injury or death attributed to the radiation aspects and that there have been no releases from nuclear power shipments. Holmes and Narver estimate that nuclear power transportation activity will exceed one million miles in 1980 and 10 million miles after 2000.

Using current statistics, Holmes and Narver estimated there will be 1.3 accidents per million vehicle miles in 2020, with total accident frequency less than one per year in 1975, then increasing to one per month after 2000, and reaching almost two per month in 2020.

Up until about year 2005, spent fuel transportation will dominate. Plutonium transportation increases dramatically after 1995 and exceeds spent fuel transportation after 2005. Shipment of radioactive waste does not exceed 10 percent of the total until after 2000; shipments of radioactive gases comprise less than 2 percent of the transportation activity.

Holmes and Narver estimated the amount of radioactivity released from the transportation activity in the nuclear power industry from 1975 to 2020 based on transportation data, estimates of the fraction of radioactivity released during an accident, and the fractions of accidents of given severity associated with damages of given severity. These results were averaged by transportation mode, accident severity, release probability, and package damage severity. The estimated average annual releases of radioactivity are summarized in table 5-9, with the largest average release of radioactivity occurring from spent fuel. The average annual whole body population dose associated with transportation accidents is shown in figure 5-7 for the period 1975-2020.

In WASH-1238, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," AEC analyzed the potential impact on the environment of transporting fuel and low level solid radioactive wastes for single light-water-cooled nuclear power plants. AEC determined that, under normal conditions of transport, the radiation dose to the individual receiving the highest exposure is

Table 5-9. Estimated average annual release of radioactivity *(5.31)*

Year	Average annual release (Ci)					
	Spent fuel			Plutonium	High-level radioactive solid waste	Noble gas
	^{85}Kr	^{131}I	Fission product			
1975	0.55	7.4×10^{-6}	0.16	3.5×10^{-4}		
1980	1.4	2.0×10^{-5}	0.46	9.5×10^{-4}		
1985	2.9	3.7×10^{-5}	0.93	2.1×10^{-3}	6.5×10^{-3}	0.27
1990	5.7	4.4×10^{-4}	1.4	2.9×10^{-3}	1.7×10^{-2}	0.76
1995	8.8	2.7×10^{-3}	2.2	4.4×10^{-3}	3.7×10^{-2}	1.8
2000	10	8.9×10^{-3}	3.4	7.6×10^{-3}	6.7×10^{-2}	3.8
2005	12	1.7×10^{-2}	4.4	1.1×10^{-2}	8.6×10^{-2}	5.9
2010	13	2.2×10^{-2}	5.5	1.4×10^{-2}	0.12	7.6
2015	13	2.7×10^{-2}	5.9	1.6×10^{-2}	0.16	10
2020	13	3.1×10^{-2}	6.3	1.7×10^{-2}	0.19	11

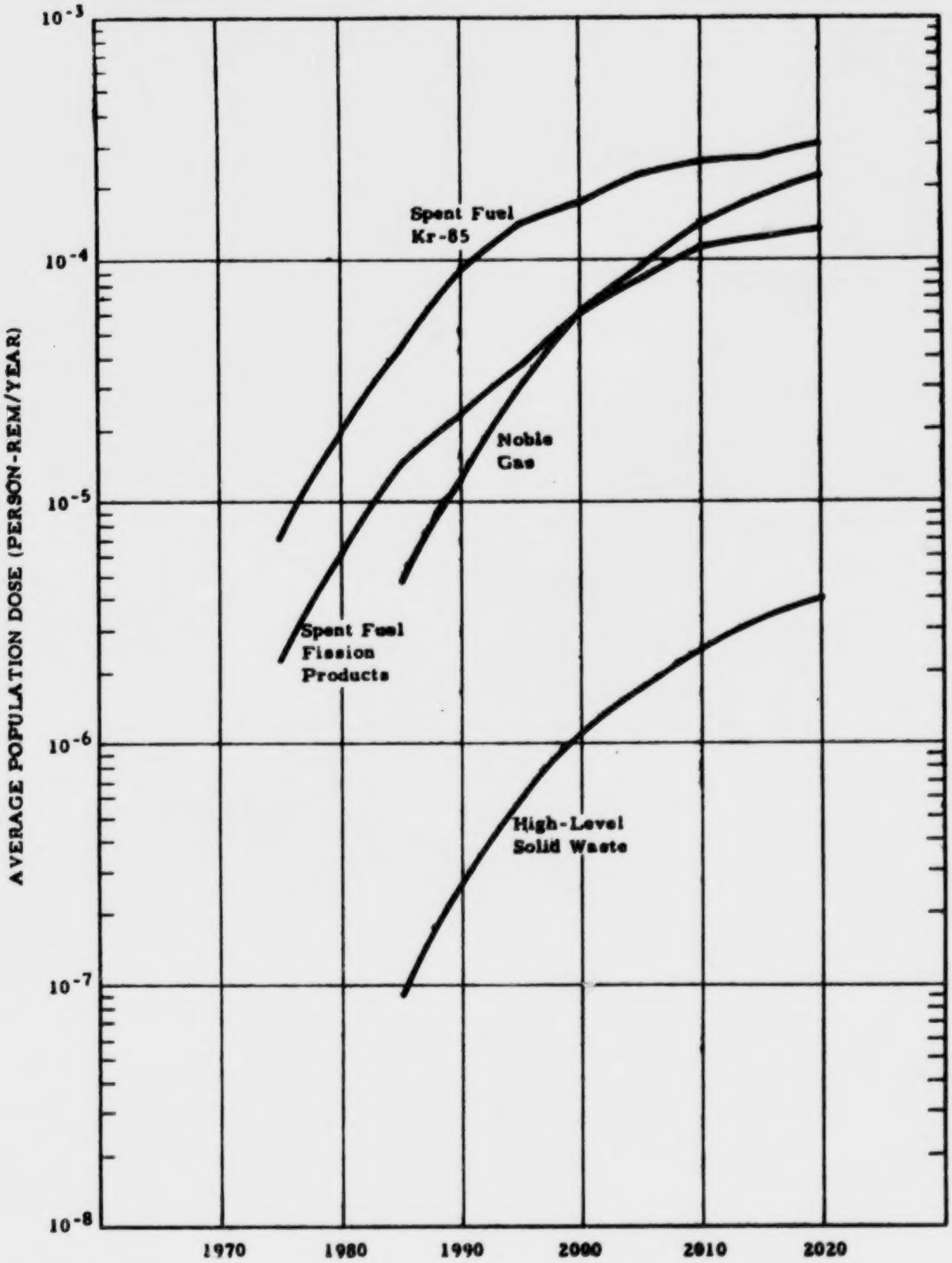

Figure 5-7. Annual average whole body population dose from transportation accidents in the nuclear power industry *(5,31)*

unlikely to be more than 500 mrem/y and the average radiation dose to those individuals in the highest exposed group is about 100 mrem/y *(5.32)*. The cumulative radiation dose to all transport workers is about 4 person-rem per reactor-year, to other persons about 3 person-rem per reactor-year distributed among approximately 600,000 people *(5.33,5.34)*. AEC felt this generic analysis would serve to implement section 102(2)(c) requirements of the National Environmental Policy Act of 1969 (NEPA), under which applicants for an AEC license to operate light-water nuclear power plants must evaluate the environmental impact of transportation of nuclear fuel and low level solid radioactive wastes to and from the plant. WASH-1238 served as the primary data base for the AEC amendment to 10 CFR 51 which permits the reactor licensing applicants in their environmental reports and AEC in their environmental impact statements to state that the adverse impact resulting from the transportation of spent fuel and packaged wastes from reactors falls within the values contained in the regulations *(5.34)*.

The Environmental Protection Agency has agreed that the values in the transportation impact table in 10 CFR 51 are reasonable for the routine impact of normal transportation; however, the Agency feels that the impact resulting from transportation accidents or incidents is not clearly defined *(5.35,5.36)*. The DOT and AEC philosophy regarding transportation safety is that safety is provided through the use of special shipping containers. EPA feels that the relationship between packaging test requirements and the survival of such packages under various accident conditions has not been established. There are current efforts by both EPA and the Energy Research and Development Administration (ERDA) (and/or NRC) to more fully assess the radiological impact of transportation accidents.

Transportation of radioisotopes

Currently, the vast majority of radioactive shipments are small or intermediate quantities (called type A quantity) of material in relatively small packages. The Office of Hazardous Materials, DOT, reported in 1972 that shipments of radioactive materials amounted to approximately 800,000 packages per year in the United States *(5.28)*. Most of these packages involve radioisotopes which are intended for medical diagnostic or therapeutic applications, and because of the short "half-life" of many such materials, these shipments are often shipped by the fastest route possible, which is air transportation. EPA, which is responsible for radiation directly or indirectly affecting health, including guidance to Federal Agencies in the formulation of radiation standards, has made recommendations of actions that could be taken to reduce passenger exposure to shipments of radioactive materials on passenger aircraft. These recommendations resulted from AEC investigations of exposure levels on passenger aircraft carrying radioactive materials. The radiopharmaceutical source, known as a molybdenum-technetium (Mo-Tc) generator, currently is the radioactive material shipped by air which poses the greatest threat of exposure to aircraft travelers. Studies sponsored by the AEC at two airports in 1973 observed a maximum radiation level at seat height of 20 mR/h on one flight carrying radioactive material. Most flights had no discernible radiation exposure to passengers. The exception was due to noncompliance with DOT regulations. The AEC estimated the average dose to aircraft passengers who travel frequently to be about 20 mR/y although, under unlikely circumstances, the dose to an individual could be as high as 160 to 170 mR/y. The EPA, AEC, and a special study group of the Joint Committee on Atomic Energy have suggested methods for reducing air passenger exposure to Mo-Tc, including increasing package shielding from 25 lbs. to about 58 lbs., using surface (truck) transport on short hauls, modifying shipping schedules of the generators, and substituting ^{99m}Tc for Mo-Tc generators *(5.37)*.

Summary

The transportation of radioactive materials is concerned with the transfer of byproduct, source and special nuclear materials. It has been estimated that the population dose in the United States due to routine transportation of radioactive materials concerned with the nuclear power industry is a very small fraction of the total annual population doses from all other sources. The annual population dose is expected to increase as the nuclear power industry expands during the next generation and will vary from 100 person-rem/y in 1975 to 8000 person-rem/y in 2020, with the largest percentage of population dose resulting from the transportation of low-level waste from the reactors to burial grounds.

Most of the small packages of radioactive material are shipped by air and are intended for medical diagnostic, therapeutic or scientific purposes. The half lives of these materials are generally short. For this reason, there generally is no discernible radiation exposure to passengers, although under unusual circumstances the individual dose rate could reach as high as 170 mrem/y.

Reprocessing Operations and Spent Fuel Storage

Spent fuel from nuclear power plants is reprocessed in order to recover isotopes of plutonium and uranium. The separation of these useful radionuclides from the spent fuel results in large quantities of radioactive waste products. Therefore, the waste management program is of great importance at a nuclear fuel reprocessing plant and the controlled discharge of low level wastes from the plant to the environment is very carefully monitored.

Since 1972, there have been no operating commercial reprocessing plants in the United States. The Nuclear Fuel Services plant in West Valley, N.Y., operated from 1966 to December 1971, but was shut down to expand its reprocessing capability to 750 tons of fuel per year.

There are three commercial fuel reprocessing plants operated for the U.S. government. In addition to the Nuclear Fuel Services plant in West Valley, N.Y., a reprocessing plant is under construction at Barnwell, S.C., but it is not expected to begin operation before 1978. The future of the Midwest Recovery Plant near Morris, Ill., which has been under construction, is uncertain. In 1973, it was operating under an AEC license as a spent fuel storage facility.

Spent fuel is stored in special storage pools at power plants for varying periods of time before being shipped to a reprocessing plant. As a consequence of there being no commercial reprocessing plant in operation since 1972, some fuel is stored at facilities at Morris, Ill., and at NFS, West Valley, N.Y. The facility at Barnwell, S.C., is in the process of obtaining a license for spent fuel storage.

Description of the data base

Characterization of the gaseous and liquid effluents from nuclear fuel reprocessing plants shows the important radioactive components to be ^{85}Kr, ^{129}I, ^{3}H, ^{106}Ru, ^{90}Sr, ^{134}Cs, ^{137}Cs, uranium and plutonium *(5.38,5.39)*. General treatment of the assessment of the effects of nuclear fuel reprocessing plants on the environment is included in some reports *(5.40-5.42)*.

Environmental monitoring reports are filed semiannually with the NRC *(5.8)* by the operators of reprocessing plants as a requirement for their operation. These reports are available to the public at NRC public document rooms. Where spent fuel is stored at nuclear power plants or reprocessing plants, the waste management procedures are combined in one program and, therefore, separate environmental monitoring reports are not required. The data that are required in the reports to NRC are included in the technical specifications of the operating license for the facility. At the NFS plant in West Valley, N.Y., the quarterly reports for 1971 and 1972 contain information on ^{131}I concentration in three milk samples and gross alpha and beta concentrations in samples collected at perimeter monitoring stations.

New York State Department of Environmental Conservation maintains a surveillance program at the NFS site and publishes an annual report which includes the data collected *(5.10,5.11,5.43)*. A summary of environmental surveillance through 1972 at NFS is included in a report by Terpilak and Jorgensen *(5.43)*. The Division of Radiological Health of the South Carolina State Board of Health has a preoperational surveillance program *(5.10,5.11,5.44)* at the Barnwell site.

Besides the sources of environmental monitoring data cited above, special studies have been carried out at the NFS site during its period of operation. Iodine-129 found in samples of milk, animals, and other environmental samples is the subject of several reports *(5.45-5.48)*. Measurements of environmental levels of radioactivity due to gaseous

(5.39,5.49) and liquid *(5.38)* effluents were made in field studies by the EPA, Office of Radiation.Programs. Aerial measurements of radioactivity were made periodically by the AEC *(5.50)*. Other surveys of environmental radiation from NFS have been conducted by New York State *(5.51-5.53)*.

Dose data

Dose data are generally lacking in environmental monitoring reports filed with the NRC by fuel reprocessing plant licensees. However, several studies made by government agencies have reported dose information based on plant effluent data and on field measurements.

A report by the Office of Radiation Programs, EPA, which develops the concept of environmental dose commitment to populations, projects doses over a 50-year period from 1970 to 2020 from normal operations of the nuclear power industry in the United States including fuel reprocessing plants *(5.22)*. Magno, et al. *(5.21)* estimates that population dose from ^{14}C may be significant. Russell and Galpin *(5.54)* in a review of offsite doses from fuel reprocessing plants indicate that radioactive iodine and krypton-85 are the most important gaseous effluent components in terms of dose to the public.

The Office of Radiation Programs of EPA in a report *(5.55)* estimating ionizing radiation doses in the United States from the year 1960 to 2000, includes dose data from reprocessing plants. The report calculates the average annual dose (whole body) accrued to the population within 100 kilometers of a fuel reprocessing plant, processing LWR fuel to be 0.17 mrem/person/y, and 6.3 mrem/person/y at a distance of 3,000 meters. Shleien *(5.56)* calculated whole-body doses using the individual dose commitment concept, i.e., the dose delivered (in mrem) to a critical organ during a 50-year period from a particular intake. The individual dose commitment was based on field measurements of environmental activity at the NFS plant site during 1968. For the "maximum individual," the whole-body dose commitment from ingestion of cesium-137 and cesium-134 (mostly from deer meat) was estimated to be 257 mrem. For the "typical individual," the whole-body dose commitment from cesium-137 was 1.7 mrem, and this was attributed mainly to the dose from fallout. Another study by Martin *(5.57)*, using effluent and environmental surveillance data from the NFS site for 1971, found the most significant radionuclides contributing to dose were tritium, krypton-85, strontium-90, cesium-137, and cesium-134. The average annual (for 1971) whole-body dose to individuals in the maximum exposure group was calculated to be 5.8 mrem and the whole body population dose was 23 person-rem. An in-depth survey of the intake of fish and venison caught in the vicinity of NFS in 1971 by Magno, et al. *(5.58)* resulted in the calculated maximum, whole body, individual dose from fishing to be 1.4 mrem and from ingestion of venison (in 1970) to be 14 mrem. These figures are considerably smaller than the doses estimated by Shleien for 1968 *(5.56)*.

The Environmental Impact Statement for the Barnwell reprocessing plant under construction predicts the maximum, whole-body dose from normal plant operations to be 4 mrem/y *(5.59)*.

Summary

There has been no commercial fuel reprocessing plant in operation in the United States since December 1971. The Nuclear Fuel Services plant operated from 1966 to 1971, and so the data reviewed in this report are for this plant during its period of operation.

Spent fuel is stored in special pools at individual nuclear power plants and at storage areas at NFS and Morris, Ill.

Dose estimates are generally not included in reports by spent fuel storage and reprocessing licensees. However, State and U.S. government agencies have collected data and reported dose information in several studies.

Reprocessing operations and spent-fuel storage is concerned with conducting a safe waste management program with a view of recovering selected isotopes and controlling the discharge of low-level wastes to the environment. It has been estimated that the average annual whole body dose to an individual within 100 kilometers of a fuel reprocessing plant is 0.17 mrem/y and 6.3 mrem/y at a distance of 3000 meters. It appears that the most significant radionuclides contributing to this dose are ^{3}H, ^{85}Kr, ^{90}Sr, ^{134}Cs, and ^{137}Cs.

Radioactive Waste Disposal

High level wastes are presently stored in retrievable form in storage areas on installations operated by contractors for ERDA. Low level radioactive wastes are also buried at these facilities. The population exposures from these waste disposal operations are included in the discussion of ERDA facilities in Chapter 6.

The disposal of low-level radioactive wastes at commercially-operated burial sites began in 1962 at Beatty, Nev. Since that time, the industry has expanded to include three private companies operating six sites. The other five sites are located in Maxey Flats, Ky.; Sheffield, Ill.; Barnwell, S.C.; West Valley, N.Y.; and Richland, Wash. The three companies operating these facilities are Nuclear Engineering Company (Washington, Nevada, Illinois, and Kentucky); Chem Nuclear Systems, Incorporated (South Carolina); and Nuclear Fuel Services (New York) *(5.60)*.

These burial facilities consist of trenches in which the waste materials are stacked and then covered by earth and compacted by earthmoving equipment. The filled trenches are then capped with a mound of earth to reduce infiltration from precipitation. In the wetter, eastern United States, precipitation presents operational problems. At two sites which have burial media with relatively low permeability, operational experience indicates that it is difficult to keep water from getting into the trenches. Compaction during backfilling, capping with mounds of earth, the placement of sumps in the trenches, and dewatering by pumping are methods now being used to deal with this problem. Because of equipment movement or waste shrinkage, the earthen caps sometimes subside and allow infiltration of water into the trenches. At some sites, growth of vegetation is encouraged to prevent erosion, while at other sites, the cap is kept barren to avoid radionuclide reconcentration by long-rooted plants.

Data base description

Most information on the quantities and types of radioactive materials in commercial burial sites is available from NRC *(5.61,5.62)*. The EPA Office of Radiation Programs also contracted with each of the six States to obtain inventories of by-product, source, and special nuclear materials buried through 1973 *(5.60)*. In addition, the quantities of liquid waste received at the burial facilities for solidification and burial were also tabulated. Some surveillance data are also presented in State reports on environmental radiation *(5.63)*.

Data base analysis

An evaluation of the available data by ORP resulted in the following observations regarding quantities of waste in burial sites *(5.60)*. In 1973, approximately 1.75 million cubic feet of waste containing approximately 300,000 curies of by-product material, approximately 150,000 grams of special nuclear material, and approximately 245,000 pounds of source material were buried at the commercial disposal facilities. The quantity and activity of these wastes are expected to increase exponentially along with the growth of nuclear power, and in the year 2000, it is estimated that as much as 80 - 100 million cubic feet of waste containing some 19 million curies of by-product material, some 7 million grams of special nuclear material, and some 11 million pounds of source material will be buried annually (These estimates are based on present rates of burial).

Surveillance information

Radioactive contamination has been detected migrating from the disposal site to the environment at the Maxey Flats and West Valley facilities. Specific radionuclides, detected in leachates in the trenches and free to migrate to the offsite environment, included: ^{3}H, ^{22}Na, ^{54}Mn, ^{55}Fe, ^{57}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{125}I, ^{129}I, ^{131}I, ^{133}Ba, ^{137}Cs, ^{226}Ra, ^{228}Ac, ^{229}Th, ^{232}Th, ^{234}U, ^{235}U, ^{236}U,

^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am. Little is known at this time about the physical and chemical characteristics of the wastes or of the radioactive contaminants being leached from them. A striking similarity has been noticed, however, between the leachates at Maxey Flats and West Valley and the leachates found at sanitary landfills. Both appear to have a high dissolved solids content (~500,000 ppm) and significant amounts of organic and inorganic acids.

Population doses

There is no information on potential doses to individuals or the general population from low-level waste burial practices. However, two of the commercial burial sites, the West Valley and Maxey Flats disposal facilities, have failed to perform as planned. Authorization to operate the burial facilities was based on analyses of the site hydrology, meteorology, etc., which, it was believed, demonstrated that the buried radioactive wastes would not migrate from the site. That is, they would be retained on the site for hundreds of years. In 10 years or less, radioactivity has been detected offsite.

Studies supported by the Office of Radiation Programs (EPA) at these two sites show similar patterns of burial and causes for the migration of pollution. Summarized simply: (1) the wastes are buried in large trenches and covered with earthen caps; (2) precipitation infiltrates through the caps, fills the trenches, and soaks the wastes; (3) the water in the trenches forms a leachate and leaches radioactive material from the wastes; and (4) the leachate and radioactive material contained therein migrate from the trenches to the uncontrolled environment *(5.64)*.

State regulatory authorities have evaluated present levels of contamination and have stated that the activity detected in the environment does not create a public health hazard, but that it does demonstrate the need to determine the possible extent of migration of radioactive material and to assess the long-range significance of its migration.

Conclusions and recommendations

There is no current indication of significant environmental levels of radionuclides from low-level waste burial sites. The goal in the design of land burial facilities is zero release. However, in the more humid Eastern United States, present disposal practices are not meeting this goal at the two burial facilities which the Office of Radiation Programs has investigated. Some contamination of local ground and surface waters is presently occurring; the significance of which is being investigated.

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Chapter 6 - Federal Facilities

There are two groups of federal facilities that handle radioactive materials and publish reports of their monitoring activities. These groups are those facilities that are operated for the Energy Research and Development Administration and the Navy's nuclear fleet and their support facilities.

ERDA facilities

There are 28 facilities that report their environmental surveillance results to the Energy Research and Development Administration (ERDA) *(6.1-6.28)*. The operators of these facilities are contractors for ERDA and operate facilities that have a potential for environmental impact or may release a significant quantity of radioactive or nonradioactive wastes. In accordance with the ERDA Manual Chapter 0513, these contractors prepare annual reports containing data on levels of radioactive and nonradioactive pollutants in the environs of each site and an interpretation of the sampling results in relation to the appropriate standards for environmental protection. These reports may also include estimates of offsite exposures and summaries of effluent releases that may be necessary to aid in calculations of any offsite exposures *(6.29)*.

Many of the monitoring reports submitted to ERDA by their contractors contained an assessment of the radiation exposure of the public which could have resulted from site operations during the past calendar year. Each of these assessments provided an estimate of (a) the "fencepost" dose at the location of the site boundary where the maximum exposure rate exists, (b) the dose to an individual and population group in those locations where the highest dose rate occurs, and/or (c) the 80-kilometer (50-mile) person-rem whole body dose. The latter dose is the dose received by the population within an 80-kilometer radius of the facility.

The annual reports were investigated for two types of doses. The first is the boundary dose or the dose to an individual at the perimeter of the secure area of the contractor facility. Twenty-three of the 31 sites (several of the facilities consist of more than one site) reported

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boundary doses; these doses ranged from a low of 13 μrem/y at the National Accelerator Laboratory to a high of 320 mrem/y at the Argonne National Laboratory.

In addition to reporting the boundary doses due to the activities of a facility, many facilities also reported a background dose that they measured as part of their monitoring program. These background doses, which are a measure of the ambient radioactivity in the environment around these contractor facilities, ranged from 54 mrem at the Knolls Atomic Power Laboratory's Kesselring Site to 200 mrem/y at the Rocky Flats Plant.

The second dose estimate that some of the contractor facilities reported is the dose to the population within 80 kilometers (50 miles) of the site. The majority of the facilities reporting an 80-kilometer population dose reported these doses in the units of person-rem. Some of these facilities, however, reported their doses in units of μrem/y. Brookhaven National Laboratory, the Feed Materials Production Center, and the Paducah plant reported doses for radii smaller than 80 kilometers. For those facilities that did report comparable person-rem doses, the doses ranged from 8×10^{-7} person-rem at the Pantex Plant to 196 person-rem at the Savannah River Plant.

The dose to an individual or population group at those locations where the highest dose rate occurs was presented by very few facilities and, consequently, was not tabulated. In many cases, this dose corresponded to the dose at the site boundary and, in all instances, was equal to or less than the dose at the site boundary. Consequently, only the doses at the site boundary and the 80-kilometer doses are tabulated in table 6-1.

Department of Defense

Of the facilities using radioactive materials in the Department of Defense, one that issues a report on its environmental program is the nuclear Navy.

At the end of 1973, the U.S. Navy had 103 nuclear-powered submarines and 4 nuclear-powered surface ships in operation *(6.30)*. Nine shipyards, 11 tenders, and two submarine bases are involved in the construction, maintenance, overhaul, and refueling of these nuclear propulsion plants.

The Navy monitoring and radioactivity control program begins with tight surveillance and control of radioactive releases and waste disposal. The radiation monitoring program consists of analyzing harbor water and sediment samples for radioactivity associated with nuclear propulsion plants, monitoring of radiation around the perimeter of support facilities, and monitoring of effluents. The primary radionuclides of concern are cobalt-60 and tritium. The total radioactivity, less tritium, discharged to all ports and harbors from these facilities was less than 2 millicuries

Table 6-1. Boundary and 80-km doses around ERDA contractor facilities, 1973 *(6.1-6.28)*

Facility Name and Location	Background Doses (mrem/y)	Boundary Dose to Individual in Population Due to Facility (mrem/y)	Population Dose within 80 km Radius around Facility (person-rem/y)	Population within 80 km of Site	Dose within 80 km Radius of Site (μrem/y)
Ames Lab. Ames, Iowa	(a)	<5	11.6	590,500	(a)
Argonne National Lab. Argonne, Ill.	100	320	94.9	7.76×10^6	12
Atomics International Canoga Park, Calif.	(a)	(a)	(a)	(a)	(a)
Battelle Columbus Lab. Columbus, Ohio	140	2.9×10^{-6}	2.7×10^{-6}	6.23×10^5	(a)
Bettis Lab. Pittsburgh, Pa.	(a)	2.4	.21	3.1×10^6	(a)
Brookhaven National Lab. Upton, N. Y.	85	15.5	.1	[b]31,700	(a)
Elk River Reactor[c] Elk River, Minn.	(a)	(a)	(a)	(a)	(a)
Feed Materials Production Center, Fernald, Ohio	(a)	9.2	(a)	(a)	[d]2,000
Hanford Site Richland, Wash.	~80	(a)	40	2.5×10^5	(a)
Knolls Atomic Power Lab.					
Knolls Site Niskayuna, N. Y.	125	<2	(a)	(a)	(a)
Kesselring Site West Milton, N. Y.	54	<.1	(a)	(a)	(a)
Windsor Site Windsor, Conn.	(a)	<.1	(a)	(a)	30
Lawrence Berkeley Lab. Berkeley, Calif.	80-100	30	<60	(a,	(a)

Table 6-1. Boundary and 80-km doses around ERDA contractor facilities, 1973 continued

Facility Name and Location	Background Doses (mrem/y)	Boundary Dose to Individual in Population Due to Facility (mrem/y)	Population Dose within 80 km Radius around Facility (person-rem/y)	Population within 80 km of Site	Dose within 80 km Radius of Site (μrem/y)
Lawrence Livermore Lab. Livermore, Calif.					
Livermore Site Site 300	71 80	.3 mrem from T (a)	3.9 from ^{41}Ar (a)	4.6 x 10^6 (a)	.85 (a)
Los Alamos Scientific Lab. Los Alamos, N. Mex.	153	(a)	0.4 from T	19,000	[e] 2000
Mound Lab. Miamisburg, Ohio	140	1.1-Whole Body-T 9.9-Bone-^{238}Pu .11-Kidney-^{210}Po	51	2.8 x 10^6	(a)
National Accelerator Lab. Batavia, Ill.	105	.013	<1	(a)	(a)
National Reactor Testing Sta. Idaho Falls, Idaho	188	<.298	.53	6.95 x 10^4	(a)
Nevada Test Site Mercury, Nev.	123	(a)	(a)	(a)	(a)
Oak Ridge Facilities Oak Ridge, Tenn.	100	130	14	7.2 x 10^5	100
Paducah Gaseous Diffusion Plant Paducah, Ky.	125	36 to lung	(a)	(a)	[f] 5000
Pantex Plant Amarillo, Tex.	(a)	.04 from depleted U 1 x 10^{-5} from T	8 x 10^{-7} from depleted U 1 x 10^{-8} from T	2.31 x 10^5	(a)
Pinellas Plant St. Petersburg, Fla.	120	.06 from T gas and tritium oxide	2.44	1.52 x 10^6	1.6
Portsmouth Gaseous Diffusion Plant Piketon, Ohio	119	6	(a)	>500,000	(a)

Table 6-1. Boundary and 80-km doses around ERDA contractor facilities, 1973 continued

Facility Name and Location	Background Doses (mrem/y)	Boundary Dose to Individual in Population Due to Facility (mrem/y)	Population Dose within 80 km Radius around Facility (person-rem/y)	Population within 80 km of Site	Dose with 80 km Radius of Site (µrem/y)
Project Rio Blanco Rio Blanco County, Colo.	146	(a)	(a)	(a)	(a)
Rocky Flats Plant Golden, Colo.	~200	(a)	(a)	(a)	(a)
Sandia Lab. Albuquerque, N. Mex.	(a)	0.014	(a)	(a)	(a)
Savannah River Plant Aiken, S. C.	60-70 mR/y	1.27	196	4.65×10^5	(a)
Shippingport Atomic Power Sta. Shippingport, Pa.	(a)	<.08	(a)	[g]18,000	<2,000
Stanford Linear Accelerator Center Stanford, Calif.	82	3.9	(a)	(a)	(a)

[a] Not reported.

[b] Assumed population within 10 km radius.

[c] The Elk River Reactor was shut down in 1968 and was being dismantied in 1973.

[d] Population at 4 km from site.

[e] Not considered statistically significant.

[f] Dose at 3.2 km from plant.

[g] Population within 8 km radius.

in 1973. The total tritium released to all ports and harbors was less than one curie in 1973. Based on the radioactivity released, the maximum radiation dose to any member of the general public in 1973 was less than 10 microrems.

Summary

Radiation exposure resulting from the operation of federal facilities is assessed by evaluating (a) the fencepost dose at the site boundary location where the maximum exposure rate exists, (b) the dose to an individual and population group in locations where the higher dose rates occur and (c) the whole body dose received by the population within a radius of 80 kilometers of the facility. The data have been compiled for 1973 and are presented in table 6-1. There are 28 federal facilities conducting nuclear operations. Based on the facilities reporting, individual and population doses showed the following ranges:

Individual dose at fence post boundary	Population dose within 80 km radius
13 - 320 mrem/y	8×10^{-7} - 196 person-rem/y

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Chapter 7 - Accelerators

The purpose of this section is to present information concerning accelerator-induced radioactivity in the environment and resulting doses to man. The availability of data encountered during the review of literature for this report concerning these aspects of accelerator operations limits this section to those facilities reported upon by the U.S. Atomic Energy Commission *(7.1-7.4)*.

These facilities are the National Accelerator Laboratory, the Brookhaven National Laboratory, the Lawrence Berkeley Laboratory, and the Stanford Linear Accelerator Center. Doses and exposure information obtained from reference *7.1* for these facilities are summarized below.

National Accelerator Laboratory

The National Accelerator Laboratory (NAL) facility is a proton synchrotron with a design energy of 200 GeV; however, it has been routinely operated at 300 GeV and at 400 GeV during a few weeks in 1973. Radioactivity is produced from the interaction of accelerator protons with matter. The induced radioactivity is mostly contained in insoluble shields and in beam dumps. The remainder penetrates the shielding, escapes as airborne radioactivity, or results in radioactivation of the soil. NAL conducts an extensive monitoring program to monitor penetrating radiation, airborne radioactivity and waterborne radioactivity. The results of the programs are presented below.

Penetrating radiation

During the year, monitoring was conducted at numerous locations around the accelerator on an around-the-clock basis. At a location where beam losses were typical of the Main Ring, there were 15 days when radiation levels were greater than 50 percent above background. Assuming that losses of the same magnitude occurred everywhere else about the Main Ring, a site boundary dose of 0.013 mrem for 1973 was calculated. At one source around the Main Ring radioactivity greater than background was detected for 160 days. The site boundary dose from that source was estimated to be less than 1/10 of 1 percent of the 1973 AEC criterion of 0.17 rem (maximum).

Additionally measurements were taken to determine if penetrating radiation existed near the site boundary along the straight line extension of the beam lines. No activity above background was detected.

Airborne radioactivity

Radioactivation of air may occur in the vicinity of some beam dumps and target boxes during operations of the accelerator. Monitoring measurements were made at the exhaust fan in the Neutrino Area Train Spur Stack. The highest concentration observed was 15 $\mu Ci/m^3$. Using a Gaussian Plume diffusion model, typical wind conditions, and a release rate of 15 $\mu Ci/m^3$, the site boundary concentration was estimated to be approximately 5×10^{-6} $\mu Ci/m^3$. The predominant activity was due to ^{11}C. This concentration equates to a 0.03 mrem/year at the site boundary. Similarly, the total exposure to the general population was estimated to be less than 1 person-rem per year.

Waterborne radioactivity

During accelerator.operation, some radioactivation of soils may occur. The radionuclides thusly induced may be leached into ground water and possibly become a mechanism for the transport of radionuclides into surface runoff waters and aquifers. Results of the NAL monitoring program indicate that a total of about 146 mCi of ^7Be was released at an average concentration of 2.5×10^{-4} $\mu Ci/m\ell$ and about 4.4 mCi of tritium was released at an average concentration of 17 pCi/ℓ during 1973. The ^7Be was released into soil at a depth of 6 feet. Due to its affinity for soil and short half life, it should not present any environmental problems when released from the soil. The tritium produced has a 12-year half life and hence its buildup in ponds on site and possible releases caused by losses from closed-loop cooling systems will require careful monitoring in future years.

In summary, the total exposure to the general population about NAL was less than 1 person-rem in 1973 and the exposure resulted primarily from ^{11}C released via the airborne pathway.

Brookhaven National Laboratory (BNL)

The major scientific facilities operated at BNL during 1973 were a High Flux Beam Reactor (HFBR), a Medical Research Reactor, the Alternating Gradient Synchrotron (AGS), the 200 MeV Proton Linac in the Brookhaven Linac Isotopes Facility (BLIF), and the Tandem Van de Graaff, 60-inch Cyclotron, Research Van de Graaff, Vertical Accelerator and Chemistry Van de Graaff for medium energy physics investigations and isotopes production.

Most of the airborne radioactive effluents at BNL originate from the HFBR, the BLIF and the Research Van de Graaff. The first two facilities produce a significant amount of the Laboratory's liquid effluents.

The contribution of the accelerators at BNL to the overall site dose to the population is not readily available from available reference material; however, the doses due to exposure from tritium can be estimated to be less than 0.05 person-rems to the population of 31,700 persons within 10 km of BNL. The exposure from accelerator "skyshine" at the closest BNL site boundary was estimated to be 1.2 millirems, mainly attributed to the neutron component of the scattered radiation from the AGS. The skyshine dose to an assumed population of 100 persons/km^2 within 3.5 km of BNL was calculated to be about 0.42 person-rems in 1973, compared to an estimated background dose of about 290 person-rems.

Lawrence Berkeley Laboratory

The Lawrence Berkeley Laboratory (LBL) is located contiguous to fairly densely populated areas, a situation which is unique among high energy accelerator laboratories. Accelerators currently operating at LBL are an 88-inch and 184-inch cyclotrons, the Bevatron, the Super Hilac, and the Electron Ring Accelerator.

An extensive program to monitor the radioactivity from accelerators and estimate doses has been carried out at LBL for a considerable period of time. The doses estimated since 1963 through 1972 are presented in table 7-1. The method of calculation of these doses is the same in all cases. The variations in dose are expected and are due to variations in accelerator operations over the years.

In 1973 the dose was estimated at a maximum to be less than 64.6 person-rem with a minimum expected dose of about 28 person-rem.

Table 7-1. Estimated dose due to LBL operations

Year	Dose (person-rem)
1963	288
1964	217
1965	110
1966	142
1967	153
1968	185
1969	277
1970	176
1971	273
1972	103

The population considered in the above estimates were from the surrounding cities of Berkeley, Oakland and Albany, California.

The dose calculated for the years in table 7-1 do not include radiation decreases due to shielding of a large fraction of the area included in the estimates by the hills of the area. Other factors that might reduce the magnitude of the dose estimates result from the inclusion of better estimates of population density and occupancy factors for close-in areas. Additionally, the estimate of neutron flux density may decrease faster with distance than assumed in the study. In view of the methods of dose estimation, it can probably be safely assumed that the calculated doses are relatively conservative.

Stanford Linear Accelerator Center (SLAC)

SLAC is a large research laboratory devoted to theoretical and experimental research in high energy physics and to the development of new techniques in high energy accelerator particles. The accelerator produces beams of electrons with energies up to 22 GeV and positrons with energies up to 12 GeV.

A surveillance program about the site is conducted to determine contributions to environmental radiation and population doses due to accelerator operations.

Because airborne radioactivity is not released until the completion of a waiting period after accelerator operations, the only radioisotope routinely released is argon-41. In addition to ^{41}Ar which results in a small contribution to environmental radioactivity and dose, fast neutrons characterized by "skyshine" are measured, and their contribution assessed.

From airborne pathway monitoring, the dose estimated at the SLAC was ≤0.05 mrem for 1973, and the dose due to penetrating radiation was about 3.9 mrem.

Investigation of activity in water and vegetation indicated that no dose would result from exposure to these potential sources.

Summary

Accelerator radioactivity is concerned with penetrating radiation (skyshine), airborne radioactivity resulting from reactivation of air to ^{11}C, and waterborne activity resulting from ^{3}H. The skyshine component is the most significant contribution to population dose. Table 7-2 summarizes the population dose from this source. No radioactivity was observed in water and vegetation, consequently, no dose can be attributed to these pathways.

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Table 7-2. Estimated population doses for 1973 from selected accelerators

Facility	Population dose (person-rem/y)
National Accelerator Laboratory	< 1
Brookhaven National Laboratory	0.42
Lawrence Berkeley Laboratory	28-65
Stanford Linear Accelerator Center	3.9

Chapter 8 - Radiopharmaceuticals

Discussed elsewhere in this report are the doses to man resulting from the use of radiopharmaceuticals in medical therapy. The uses of radiopharmaceuticals in therapy result in the major doses to man; however, additional doses to man result from the manufacture of radiopharmaceuticals and from the discharge of radiopharmaceuticals to the environment from patient and medical facilities.

A search of available literature unfortunately has not revealed any references concerning the release of radiopharmaceuticals to the environment during manufacturing processes, thus the effect of manufacture of these materials cannot be determined.

A study *(8.1)* which was concerned with the release to the environment via the nuclear medicine pathway was conducted in 1975. The study reviewed previous studies in this area and made estimates of whole body population doses in Houston, Tex., from five medical institutions. The calculated whole body doses due to the releases of ^{133}Xe was 0.083 person-rem, and the corresponding skin dose was 0.2 person-rem.

In order to estimate the total contribution to population doses from the discharges of radiopharmaceuticals, each medical facility would require evaluation because of the unique ways each might contribute to environmental contamination. Thus, it is concluded that little inference can be made at this time about the dose and contamination that results from the discharge from radiopharmaceuticals from patients and medical facilities.

Reference

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Chapter 9 - Medical Radiation

The responsibility for controlling medical exposure to radiation is divided between the Federal and the State governments. Within the Federal Government, the Bureau of Radiological Health in the Department of Health, Education and Welfare has the responsibility of administrating the Radiation Control for Health and Safety Act (Public Law 90-602). The Secretary of Health, Education and Welfare is required by the act to submit an annual report to the President for transmittal to the Congress *(9.1)*.

A model State Radiation Control Act containing suggested model regulations for control of radiation was published by the Council of State Governments with the cooperation and assistance of interested Federal Agencies *(9.2)*. This publication assisted the States in making regulations compatible with each other and with the Federal Government. Fifty states, the District of Columbia and the Commonwealth of Puerto Rico now have laws for the regulation of ionizing radiation *(9.3)*.

The use of radiation by the medical profession is recognized as the largest manmade component of radiation dose to the United States population. This includes medical diagnostic radiology, clinical nuclear medicine, radiation therapy and occupational exposure of medical and paramedical personnel. However, the main contributor of the total dose from medical exposures is diagnostic x radiation, the contribution from dental radiation, radiopharmaceuticals, and radiation therapy being far lower. Medical diagnostic radiology accounts for at least 90 percent of the total manmade radiation dose to which the U.S. population is exposed. This is at least 35 percent of the total radiation dose from all sources (including natural radioactivity) *(9.4,9.5)*.

The Bureau of Radiological Health (BRH) in cooperation with the National Center for Health Statistics (NCHS) conducted an X-ray Exposure Study (XES) in 1964 *(9.6)* and another in 1970 *(9.7)*. A dose model was developed for use in calculating the gonad dose from the XES data, and a

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report presently being prepared will illustrate changes in gonad and genetically significant dose from diagnostic x-ray procedures between 1964 and 1970.

In an interim report released last year by BRH *(9.8)*, selected highlights are presented to show some of the changes in medical x-ray use patterns between 1964 and 1970 (tables 9-1 and 9-2 and figure 9-1).

1) There was a 20 percent increase in the number of persons receiving one or more x-ray procedures from 108 million in 1964 to 130 million in 1970 while the population increased only 7 percent.

2) There was a 22 percent increase in the number of x-ray examinations performed from 174 million in 1964 to 212 million in 1970.

3) There was a 30 percent increase in the number of films exposed from 506 million in 1964 to 661 million in 1970.

4) The average number of films per radiographic examination increased from 2.2 in 1964 to 2.4 in 1970.

5) The number of thoracic examinations performed with two or more x-ray films increased from 31 percent in 1964 to 47 percent in 1970. This was largely due to the inclusion of lateral views for routine chest examinations.

6) The mean ratio of beam area to film area for radiographs declined approximately 30 percent.

7) The estimated mean skin exposure per film for posterior-anterior (PA) and anterior-posterior views of the abdomen increased from 480 mR in 1964 to 620 mR in 1970.

8) There was no significant change in the estimated mean exposure per film for radiographic PA chest examination. It was approximately 28 mR in 1964 and 27 mR in 1970.

9) There was a 20 percent decrease in the mean skin exposure per dental film from 1140 mR in 1964 to 910 mR in 1970. This decrease is indicative of a greater use of faster films.

The GSD was estimated to be 20 ± 8 mrad at the 95 percent confidence level in 1970, compared with 17 ± 12 mrad in 1964 which does not constitute a statistically significant change *(9.8)*.

Table 9-1. Estimated mean gonadal dose per examination from radiographic examinations by type of examination and by sex, United States, 1964 and 1970 (*9.8*)

Type of examination	Dose (mrad)							
	1964				1970			
	Male		Female		Male		Female	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Skull	-	-	-	-	-	-	-	-
Cervical spine	-	-	-	-	-	-	-	-
Chest								
Radiographic	1		5	1	-	-	1	-
Photofluorographic	-	-	5	1	2	2	3	-
Thoracic spine	46	55	17	8	3	3	11	2
Shoulder	-	-	-	-	-	-	-	-
Upper gastrointestinal series	22	11	122	19	1	1	171	15
Barium enema	119	47	470	48	175	70	903	111
Cholecystography or cholangiogram	-	-	71	15	-	-	78	17
Intravenous or retrograde pyelogram	535	172	437	43	207	66	588	47
Abdomen, KUB, flat plate	63	21	248	41	97	42	221	25
Lumbar spine	108	39	507	66	218	98	721	50
Pelvis	443	101	119	20	364	76	210	34
Hip	718	244	196	31	600	135	124	15
Upper extremities	-	-	1	1	-	-	-	-
Lower extremities	38	11	-	-	15	7	-	-
Other abdominal exams	296	178	213	43	857	332	524	84
All others	1	1	4	2	-	-	6	4

— = less than 0.5   S.E. = standard error

Table 9-2. Estimated radiographic examination rates by type of examination and sex, United States, 1964 and 1970 (*9.8*)

Type of examination	Estimated rate per 1000 persons							
	1964				1970			
	Male		Female		Male		Female	
	Rate	S.E.	Rate	S.E.	Rate	S.E.	Rate	S.E.
Skull	17	6	15	6	25	4	17	3
Cervical spine	11	3	16	6	17	4	15	3
Chest								
Radiographic	181	20	167	18	253	13	234	12
Photofluorographic	84	13	89	13	45	6	58	6
Thoracic spine	8	5	6	4	7	2	8	2
Shoulder	8	5	8	46	10	3	10	3
Upper gastrointestinal series	31	19	29	8	34	5	34	5
Barium enema	14	6	18	7	16	4	19	4
Cholecystography or cholangiogram	12	6	18	7	16	4	24	4
Intravenous or retrograde pyelogram	20	7	15	6	20	4	19	4
Abdomen, KUB, flat plate	22	7	10	5	17	4	17	3
Lumbar spine	22	7	21	7	31	5	24	4
Pelvis	12	6	11	6	8	3	13	3
Hip	5	4	7	5	4	2	10	3
Upper extremities	49	11	34	9	57	6	41	5
Lower extremities	70	13	40	10	64	7	57	6
Other abdominal exams	8	3	10	5	6	4	12	5
All other	23	8	15	6	27	8	22	7

S.E. = standard error

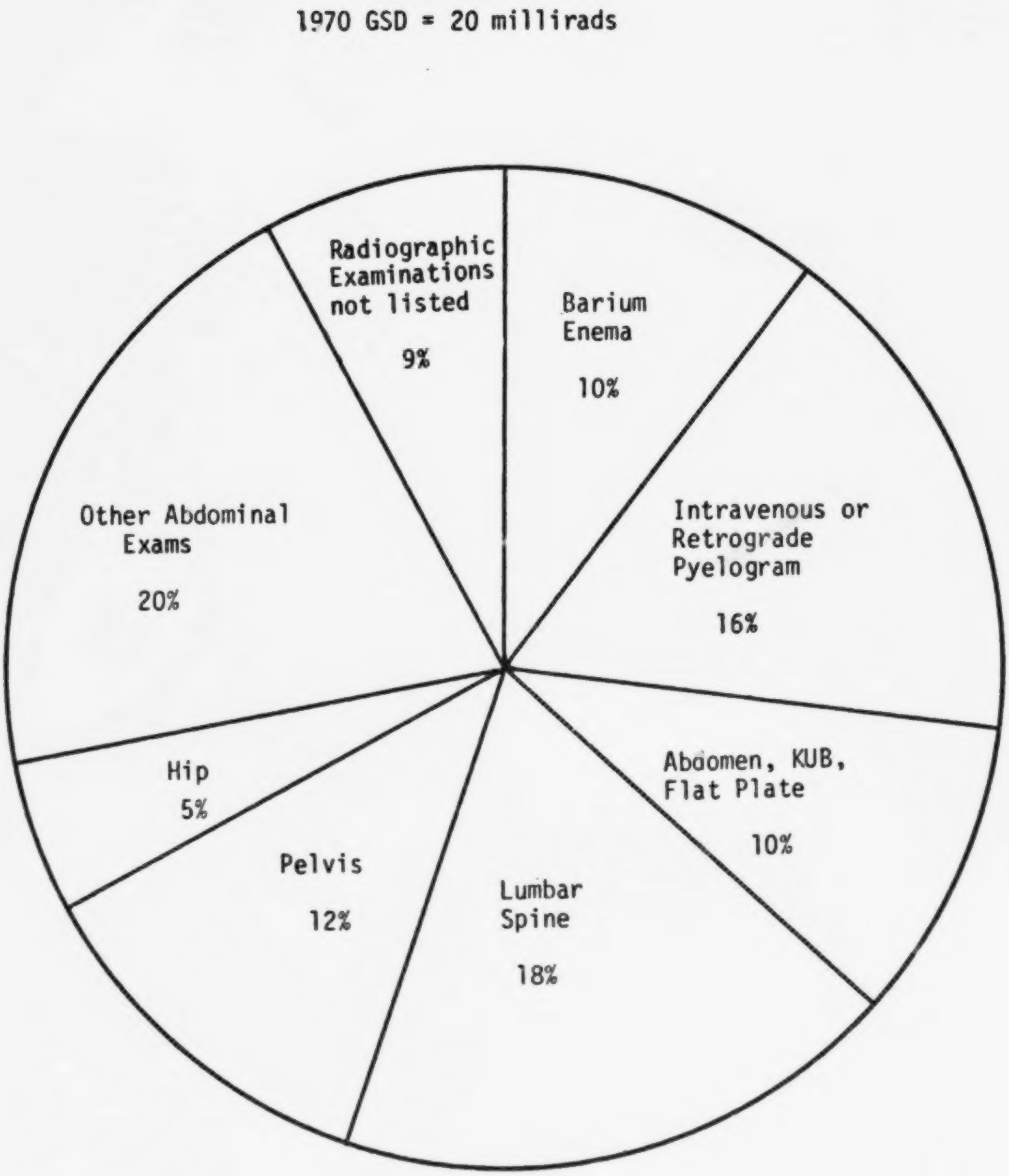

Figure 9-1. Estimated mean annual genetically significant dose contribution from radiographic examinations by type of examination, United States, 1970 *(9.8)*

Radiopharmaceuticals are used in the diagnosis and, in some cases, the treatment of disease. Their use has increased fivefold from 1960 to 1970, and it has been estimated that an increase of sevenfold may be experienced from 1970 to 1980. If this trend continues, and there are no technical changes, it is estimated that the whole-body dose to the United States population in 1980 from the use of radiopharmaceuticals will be 3.3 million person-rem *(9.5)*.

The Bureau of Radiological Health has released information on a pilot study that compares current nuclear medicine data obtained from six hospitals with survey data collected from the same institutions in previous years *(9.9)*. Although these data cannot be considered to be representative of nuclear medicine practice in all U.S. hospitals, the study notes that several significant trends are apparent *(9.10)*.

1) There has been an increase in nuclear medicine procedures of more than 17 percent per year over the past 3 years.

2) There has been a decrease in the use of iodine-131 but the use of technetium-99m has increased from 7 percent in 1966 to 82 percent in the current study.

3) The proportion of patients under the age of 30 on which nuclear medicine procedures are performed is 21 percent.

The contribution of nuclear medicine to the total medical radiation exposure to the population may be greater than previously estimated if the trends indicated in the pilot study are a reflection of the practice of nuclear medicine throughout the United States.

X rays were used by dermatologists for the treatment of skin lesions from 1930 to 1960. Since that time, there has been a great reduction in their use for this purpose and in the kilovoltage and beam penetration when used. However, there is not much dose information available on the treatment of nonmalignant diseases with radiation.

In the treatment of cancer, tumor cells are given destructive radiation doses and the exposure to healthy cells in the adjacent area is not considered an undesirable side effect. It has been estimated that radiation therapy used in the treatment of cancer contributes an additional 5 mrem to the genetically significant dose annually *(9.4)*.

Summary

Medical radiation is concerned with the doses from diagnostic x radiation, therapeutic x radiation, dental radiation and radiopharmaceuticals. The main contributor to this total dose is from diagnostic x rays. The doses from the other applications are significantly lower. The genetically significant dose from the use of diagnostic x rays in the United States in 1970 was 20 millirads. The anticipated whole body population dose from the use of radiopharmaceuticals will be 3.3×10^6 person-rem in 1980.

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Chapter 10 - Occupational and Industrial Radiation

There is surprisingly little data published in the scientific literature on the contributions of occupational exposure to the population dose from ionizing radiation. However, there is a large quantity of data available in various dosimetry programs throughout the United States *(10.1,10.2)*. In general, personnel monitoring programs are designed to check that exposures of radiation workers do not exceed some specified level. In addition, it is usual to ignore doses below a minimum detectable level or below the "investigation level" set for monitoring purposes.

The Federal Radiation Council in May 1960 recommended Radiation Protection Guides for the use by Federal agencies in their radiation protection activities *(10.3)*. These guides (table 10-1) are being reviewed by the Environmental Protection Agency, and it is anticipated that EPA recommended updated guidance will be formally submitted to the President for approval sometime in 1977.

Close adherence to the FRC Guides and the recommendations of such bodies as the International Commission on Radiological Protection, the International Labour Organization, the World Health Organization, and the International Atomic Energy Agency insures that most workers receive very low exposures and that very few workers exceed the recommended permissible doses. The maximum permissible annual dose to the whole body is about 50 times that received from natural radiation sources.

In 1970, the average dose rate from occupational sources was reported as 0.8 mrem/y *(10.4)*.

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Table 10-1. Radiation protection guides *(10.3)*

Type of exposure	Condition	Dose (rem)
Radiation worker:		
(a) Whole body, head and trunk, active blood forming organs, gonads, or lens of eye	Accumulated dose	5 times the number of years beyond age 18.
	13 weeks	3.
(b) Skin of whole body and thyroid	Year	30.
	13 weeks	10.
(c) Hands and forearms, feet and ankles	Year	75.
	13 weeks	25.
(d) Bone	Body burden	0.1 microgram of radium-226 or its biological equivalent.
(e) Other organs	Year	15.
	13 weeks	5.
Population:		
(a) Individual	Year	0.5 (whole body).
(b) Average	30 year	5 (gonads).

One of the problems encountered in dealing with occupational radiation is in defining "radiation worker." It can mean all of the staff in certain establishments, or in other work places, only those personnel whose exposures might exceed three-tenths of the annual dose limit. In 1966, the ICRP introduced the concept of a single category of occupational exposure, the radiation exposure received by any worker in the course of his work. The UN Scientific Committee reported that a representative figure for most developed countries is 1-2 workers per thousand population, with the U.S. 1970 figure being somewhat higher. The UN data for the United States reports 1.33/thousand workers engaged in medical work, 0.87 in dental, 1.55 in research and education, with a total of 3.7/thousand *(10.2)*. There are no data reported in categories termed atomic energy and industrial, and it is not clear whether the medical category includes diagnosis, therapy, chiropractic, or veterinary. Klement et al. reported 3.76 radiation workers in the United States by "using reported numbers of workers and judicious estimates in non-reported areas" *(10.1)*. The categories of workers and total annual occupational whole body doses (1969-1970) are reported in table 10-2.

There is no requirement for uniformity in collecting and reporting occupational exposures. There are considerable variations in the terminology used by reporting agencies. For example, results of personnel monitoring data are reported as exposures (R), absorbed doses (rad) or dose equivalents (rem). The dose equivalent is used frequently because this is the term used by the International Commission on Radiological Protection (ICRP) to express the maximum permissible doses for occupational exposure.

With external monitoring, there is generally little data available about the actual doses received by the various tissues; workers generally wear one dosimeter--doses to those parts distant from the monitoring device will generally be lower. The value reported is assumed to be the value of the device. "For various reasons, therefore, it is probable that the direct use of data about individual doses from personnel monitoring programmes will tend to overestimate population doses for the various tissues of interest, but, at the low levels currently involved, this is not considered to be a serious problem." *(10.2)*.

Data on licensed installations in the United States in 1968 reported in a UN report indicate that in general the great majority of exposures reported through a film badge monitoring of a sample of workers using radioactive materials are in the lower dose ranges. However, the data indicate a large percentage of waste disposal workers with exposures in high dose ranges, and this was also true to a lesser extent of industrial radiographers (table 10-3) *(10.2)*.

Accidents and overexposures are rare in most types of radiation work today. However, there are some exceptions--most reported injuries occur in industrial radiography and users of x-ray crystallographic machines. There is a problem in reducing the inhalation exposures of miners (particularly in underground uranium mining). This form of radiation exposure at sufficiently high levels has been shown to be associated with an increased incidence of lung cancer.

Table 10-2. Total annual whole-body dose by reporting group and occupation - 1969 to 1970 *(10.1)*

Activity	Air Force	Army	Navy	State Licensee	AEC Licensee	AEC	PHS	Non-federal	Nonreporting Licensee State	Nonreporting Licensee AEC
Healing arts	736	366	477	3,403	5,260		65	104,136		
Medical x ray	(405)							(62,253)		
Dental x ray	(264)							(21,403)		
Radionuclides	(53)									
Veterinary x ray	(14)									
Medical radium								(20,480)		
Industrial practice	394	269	10,402	1,784	2,891					
Radionuclides	(229)			(1,490)	(2,139)					
Radiography	(165)			(294)	(752)					
Reactors	100	73			497					
Waste disposal				766	96					
Fuel processing					2,177					
Packaging & transport					22					
Radar	96									
Special weapons	65									
Academic				499	903					
Not specified	164			226	1,024	20,361			819	5,022
Major processing				37	495					

Table 10-3. Percentage of workers in recorded dose ranges in licensed installations[a] (United States, 1968) *(10.2)*

Dose range (rad/y)	Academic	Medical[a]	Major processor	Industry general	Industry radiography	Waste disposal	Fuel processing and reprocessing	Power and research reactors	All others
0 - 0.5	96.5	87.9	88.0	91.7	75.0	46.2	86.1	95.7	94.6
0.5 - 1	2.1	7.1	4.0	3.4	10.5	6.6	5.4	2.4	3.4
1 - 5	1.4	4.7	6.8	4.7	14.0	33.8	7.4	1.7	1.8
>5	0	0.2	1.2	0.2	0.5	13.3	0.1	0.2	0.2

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[a] The data in this table apply to facilities licensed under the United States Atomic Energy Act, and do not include those workers exposed to machine-produced radiation exclusively.

There has been some difficulty in the luminizing industry in preventing excessive uptake of tritium by the workers. Tritium and, to some extent, promethium have replaced radium as the light activator in phosphors. In general, the occupational exposure to radium is higher than to tritium (and radium offers no advantage as compared to tritium). The occupational exposure to promethium-147 cannot be measured with any degree of accuracy--no data are available and none can be expected to be available because of the extreme difficulties in measuring the body burden of the workers. The chemical properties of radium and promethium are similar. Table 10-4 summarizes risks from processing 1 curie of radium, promethium-147 and tritium. Table 10-5 contains average occupational exposure to tritium as measured by Moghissi et al. and Krejci *(10.5)*.

Data on occupational exposure records from 13 U.S. operating nuclear power plants for the period 1970-72 supports the view that maintenance activities account for the major portion of in-plant exposure *(10.6)*. Tables 10-6 and 10-7 present total employee exposure data in person-rem. These tables are given an average person-rem/person-year based on the number of people employed at the plant either as utility staff or as contractors. For all the plants listed in table 10-7, the average exposure for workers is 1.16 rem/year. The PWR exposures average 1.08 rem per year; for the BWR's, the average exposure is 1.23 rem per year. Data categorized by job function are shown in table 10-8.

A program for the reporting of certain occupational radiation exposure information on monitored individuals to a central repository was approved by the AEC in 1968 and arrangements were made for the establishment of a central, computerized repository at the Union Carbide Computing Technology Center, Oak Ridge, Tenn. Information was required from four categories of AEC licensees (operating nuclear power facilities; industrial radiographers; fuel processors, fabricators and reprocessors; commercial processors and distributors of specified quantities of byproduct materials) and from AEC contractors exempt from licensing. Certain information obtained from personnel overexposure reports submitted by all licensees and contractors would also be maintained in the repository. As of December 31, 1973, these 6 types of reports had provided exposure information on a total of approximately 150,000 monitored persons (summarized and published in WASH-1350-R1 through R6) *(10.7)*.

With the division of the AEC into the two agencies, the Energy Research and Development Administration (ERDA) and the U.S. Nuclear Regulatory Commission (NRC), in January 1975, each of the agencies assumed responsibility for collecting occupational radiation exposure information relating to its own activities.

Table 10-4. Total risk from various radionuclides per Ci processed *(10.5)*

Occupation	Risk per Ci processed (person-mrem)		
	Radium	Tritium	Promethium-147
Dial Painting			
Bone	200,000	NA	Unknown
Whole body	600,000	9.1	5*
Lung	125,000	NA	Unknown
Assembly			
Whole body	69,000	4.5*	Unknown
Storage			
Whole body	Unknown	12*	Unknown
Environmental (user's dose from wristwatches)			
Whole body	$(65\text{-}70)10^6$	30	5000

*Estimated values with limited usefulness

Table 10-5. Average occupational exposure to tritium according to Moghissi, et al. *(10.5)*

Location of plants	Average activity in paint (mCi/g)	Processed tritium (Ci/person-yr)	Average urine activity (µCi/l)	Risk (person-mrem/Ci)	Reference
U.S.A.	150	104.3	20.4	19.1	Moghissi et al.
Switzerland	150	193.4	2.57	1.3	Krejci
Switzerland	227	64.9	3.43	5.3	Krejci
Switzerland	102	140.8	7.64	5.4	Krejci
Switzerland	164	222.2	13.1	5.9	Krejci
Switzerland	262	67.6	4.86	7.2	Krejci
Switzerland	354	79.6	9.57	12.0	Krejci
Switzerland	453	65.3	14.2	21.7	Krejci
Average				9.1	

Table 10-6. Summary of in-plant occupational exposures *(10.8)*

		Normal Operations				Shutdown operations						Plant total		
				Total						Total				
Plant	Year	Surveillance and inspection (person-rem)	Maintenance (person-rem)	person-rem	person-rem/ MW(e)-h	Routine refueling (person-rem)	Special refueling (person-rem)	Shutdown maintenance (person-rem)	Special maintenance and inspection (person-rem)	person-rem	person-rem/ MW(e)-h	person-rem	person-rem/ MW(e)-h	person-rem/ MW(e)-h
Ginna	1970 1971 1972	93.97 69.69 61.01	113.62 248.17 493.84	207.59 317.86 554.85	$8.971x10^{-5}$ $1.107x10^{-4}$ $2.157x10^{-4}$	82.06 115.31	7.00 14.19		23.35 347.82	112.41 477.32	$3.914x10^{-5}$ $1.856x10^{-4}$	207.59 430.27 1,032.17 1,670.03	$8.971x10^{-5}$ $1.498x10^{-4}$ $4.013x10^{-4}$	1.89
H.B. Robinson	1971 1972	7 42	3 36	10 78	$3.892x10^{-6}$ $1.101x10^{-5}$				354 139	354 139	$1.378x10^{-4}$ $1.963x10^{-5}$	364.0 217.0 581.0	$1.417x10^{-4}$ $3.064x10^{-5}$	.72
Conn. Yankee	1969 1970 1971 1972			178.8 184.8 173.0 155.6	$4.603x10^{-5}$ $4.968x10^{-5}$ $3.932x10^{-5}$ $3.445x10^{-5}$	343.0 213.9 144.2			200.9 19.2 99.0	543.9 232.1 243.2	$1.462x10^{-4}$ $5.276x10^{-5}$ $5.385x10^{-5}$	176.8 738.7 405.1 398.8 1,719.4	$4.603x10^{-5}$ $1.986x10^{-4}$ $9.208x10^{-5}$ $8.830x10^{-5}$	.89
San Onofre	1969 1970 1971 1972			41.76 49.45	$1.518x10^{-5}$ $1.426x10^{-5}$							41.76 155.48 49.45 256.94 503.63	$1.518x10^{-5}$ $4.860x10^{-5}$ $1.426x10^{-5}$ $8.665x10^{-5}$	.36
Point Beach	1971 1972	23.295	7.14	30.435	$8.832x10^{-6}$							30.435 578.864 609.3	$8.832x10^{-6}$ $1.748x10^{-4}$	.79
Indian Point	1969 1970 1971 1972											235.55 1,342.38 662.00 742.05 2,981.98	$1.304x10^{-4}$ $3.525x10^{-3}$ $4.906x10^{-4}$ $5.953x10^{-4}$	5.46
Yankee Rowe	1969 1970 1971 1972											235.604 255.248 90.3 255.25 836.4	$1.944x10^{-4}$ $1.994x10^{-4}$ $5.941x10^{-5}$ $3.699x10^{-4}$	1.57
											Total	8902	Average	1.29
Nine Mile Point	1970 1971 1972	16.03 24.59 89.88	28.68 19.20 53.86	44.71 43.79 143.74	$2.331x10^{-5}$ $1.444x10^{-5}$ $4.433x10^{-5}$	20.17 39.21		113.25 102.52		133.45 141.73	$4.400x10^{-5}$	44.71 177.24 285.47 507.42	$2.331x10^{-5}$ $5.844x10^{-5}$ $8.805x10^{-5}$	.36
Monticello	1971 1972	15.7 40.4	4.5 11.6	20.2 52.0	$1.378x10^{-5}$ $1.399x10^{-5}$				5.5 8.1	5.5 8.1	$3.752x10^{-6}$ $2.179x10^{-6}$	25.7 60.1 85.8	$1.753x10^{-5}$ $1.617x10^{-5}$	.145
Quad Cities	1972	10.92	11.53	22.45					33.49			55.94	$1.354x10^{-5}$	.119
Millstone	1971 1972	19.63 50.11	11.55 38.68	31.18 88.79	$8.321x10^{-6}$ $2.685x10^{-5}$	74.23		92.80	17.49 339.95	17.49 506.98	$4.668x10^{-6}$ $1.533x10^{-4}$	48.67 595.77 644.44	$1.299x10^{-5}$ $1.801x10^{-4}$	.80
Humboldt Bay	1969 1970 1971 1972	50.610 93.160 91.480 63.810	19.445 37.705 23.410 19.865	70.055 130.865 114.890 83.675	$1.803x10^{-4}$ $3.033x10^{-4}$ $3.313x10^{-4}$ $2.216x10^{-4}$					98.820 83.630 178.060 172.220	$2.543x10^{-4}$ $1.938x10^{-4}$ $5.134x10^{-4}$	168.875 214.495 292.950 253.895 930.215	$4.348x10^{-4}$ $4.972x10^{-4}$ $8.447x10^{-4}$ $6.776x10^{-4}$	5.28
Pilgrim	1972	10.74	4.13	14.87	$1.672x10^{-5}$				.73	.73	$8.210x10^{-7}$	15.60	$1.754x10^{-5}$	.153
Big Rock	1969 1970 1971 1972	59.5 57.0 50.5	31.5 21.0 18	91.0 79.0 68.5	$2.389x10^{-4}$ $2.333x10^{-4}$ $1.796x10^{-4}$	15 13.5 23.5	10 6.5 9.0		84 54.5 76.0	109 74.5 106.5	$2.862x10^{-4}$ $2.200x10^{-4}$ $2.792x10^{-4}$	117.60 200.0 143.5 175.0 636.1	$2.788x10^{-4}$ $5.251x10^{-4}$ $4.238x10^{-4}$ $4.588x10^{-4}$	3.66
Oyster Creek	1970 1971 1972											63.38 240.50 582.34 886.22	$1.764x10^{-5}$ $6.054x10^{-5}$ $1.293x10^{-4}$	0.64
Dresden	1969 1970 1971 1972											286.4 143.2 715.2 728. 1,872.8	$3.280x10^{-4}$ $5.341x10^{-5}$ $1.540x10^{-4}$ $7.500x10^{-5}$	0.92
											Total	5,633	Average	0.856

Table 10-7. Average employee dose *(10.6)*

Plant	Year	Total plant doses (person-rem)	Number of personnel at plant	Dose (person-rem/person/y)	Average (person-rem/person/plant-y)
Ginna	70	207.59	170	1.868	1.558
	71	430.27	340	1.266	
	72	1032.17	667	1.547	
H. B. Robinson	71	364.0	283	1.286	1.086
	72	217.0	245	.886	
Conn. Yankee	69	176.8	98	1.804	1.308
	70	738.7	601	1.229	
	71	405.1	265	1.110	
	72	398.8	267	1.087	
San Onofre	69	41.76	123	.340	.538
	70	155.48	251	.619	
	71	49.45	121	.409	
	72	256.94	326	.788	
Nine Mile Point	70	44.71	821	.054	.319
	71	177.24	1006	.176	
	72	285.47	392	.728	
Monticello	71	25.7	63	.408	.499
	72	60.1	102	.589	
Quad Cities	72	55.94	173	.323	.323
Millstone	71	48.67	244	.199	1.383
	72	595.77	232	2.568	
Humboldt	69	168.875	115	1.468	1.849
	70	214.495	115	1.865	
	71	292.950	140	2.093	
	72	253.895	129	1.968	

Table 10-7. Average employee dose (contd)

Plant	Year	Total plant doses (person-rem)	Number of personnel at plant	Dose (person-rem/person/y)	Average (person-rem/person/plant-y)
Pilgrim	72	15.60	57	.274	.274
Point Beach	71	30.435	79	.385	.986
	72	578.864	365	1.586	
Oyster Creek	70	63.38	95	.667	1.117
	71	240.50	249	.966	
	72	582.34	339	1.718	
Dresden	69	286.4	[a]182	1.574	2.127
	70	143.2	[a]202	.709	
	71	715.2	[a]225	3.179	
	72	728.	[a]239	3.046	
				Average for workers =	1.16 rem
Big Rock	69	117.60	[a]223	.527	.585
	70	200.0	[a]262	.763	
	71	143.5	[a]272	.528	
	72	175.0	[a]336	.521	
Indian Point	69	235.55	[a]519	.454	.547
	70	1342.38	[a]1864	.720	
	71	662.00	[a]1280	.517	
	72	742.05	[a]1497	.496	
Yankee Rowe	69	235.6	[b]509	.463	.335
	70	255.2	[b]698	.366	
	71	90.3	[b]501	.180	
	72	255.2	[b]769	.332	

[a] Number of personnel with >100 mrem/month.

[b] Total personnel involved at the plant. May include some with <100 mrem/quarter.

Table 10-8. Breakdown of in-plant exposures *(10.6)*
(person-rem)

Facility	Year	Contractors	Health physics	Maintenance**	Total for permanent plant personnel
Dresden	1969	70.7	22.6		215.7
	1970	15.3	14.5		127.9
	1971	399.3	48.3		315.9
	1972	360.	42.7		368.
Humboldt	1969	12.455	11.519	62.841	156.42
	1970	37.030	11.685	71.635	177.465
	1971	64.935	16.750	80.010	228.015
	1972	57.565	15.715	73.450	196.33
Nine Mile Point	1970	16.84	2.74	28.68	27.87
	1971	63.32	10.22	32.09	131.71
	1972	27.90	13.08	156.38	257.57
Monticello	1971	1.7	Not given	4.5	24
	1972	1.2	Not given	11.6	58.9
Quad Cities	1972	33.49	Not given	46	22.45
Oyster Creek	1970	11.2	5.82	26.85	52.18
	1971	92.2	11.35	81.03	148.30
	1972	167.67	28.18	229.06	414.67
San Onofre	1969	4.81	4.24	25.07	36.95
	1970	58.72	8.33	75.63	96.76
	1971	2.63	4.75	32.33	46.82
	1972	116.81	12.09	103.18	140.13

Table 10-8 (Contd)

Facility	Year	Contractors	Health physics	Maintenance**	Total for permanent plant personnel
Ginna	1970	15.30	Not given	113.62	192.29
	1971	108.43	Not given	248.17	321.84
	1972	278.36	38.24	493.84	753.81
Yankee Rowe	1969	74.74	Not given	64.034	160.864
	1970	91.75	Not given	67.088	163.498
	1971	18.71	Not given	24.960	71.59
	1972	142.14	Not given	46.300	113.11
H.B. Robinson	1971	351.	Not given	3	364.
	1972	137	Not given	36	217.
Conn. Yankee	1969	34.8	15	33	142.0
	1970	201.6*	37	27.5	326.2*
	1971	96.4*	31	92.8	309.7*
	1972	47.0*	28	79.8	252.8*
Point Beach	1971	0	5.86	7.14	30.735
	1972	480.717	14.103	35.976	98.147
Average		102.6	18.2	82.3	214.5

*Does not include special operations of which there were 200.9 person-rem in 1970, 19.2 person-rem in 1971, and 79.0 person-rem in 1972.

**Maintenance includes the normal maintenance performed during operation in addition to that performed during refueling.

For calendar year 1973, annual statistical exposure data was reported on 221,979 monitored individuals (AEC offices, contractors, and licensees). Of this total, 212,044 (95.5 percent) received annual whole body external exposures of less than 1 rem; 362 or 0.2 percent exceeded 5 rems (table 10-9) *(10.8)*. Table 10-10 indicates the distribution of whole body exposures in 1974 by 85,097 monitored individuals for 4 categories of NRC licensees *(10.7)*.

In 1974, 10 CFR 20.407 was amended to require covered licensees to submit an annual statistical summary of exposure and data rather than identification and exposure data for individuals whose annual exposure exceeded applicable quarterly limits. The new reporting system was adopted to give a much better indication of the actual distribution of whole body exposures. Table 10-11 gives a comparative analysis of AEC contractor and licensee annual exposure experience for 1968-1974 *(10.7,10.8)*.

A brief summary of annual exposures at nuclear power facilities for a 6-year period is given in table 10-12. There have been no reported annual whole body exposures exceeding 12 rems during the 6 years. "Occupational Radiation Exposure at Light Water Cooled Power Reactors 1969-1974," NUREG-75/032, contains a more detailed analysis of this information.

Section 20.405 of Title 10, Code of Federal Regulations, requires all licensees to report personnel exposures in excess of applicable limits to the U.S. Nuclear Regulatory Commission (formerly AEC). During the 4-year period 1971-1974, a total of 288 reports of personnel overexposures to external radiation were received. About 35 percent of this number occurred during industrial radiography operations; about 28 percent occurred during testing, maintenance, and/or repair activities at licensed nuclear power facilities; about 13 percent occurred during the processing and production of byproduct material. Of the remaining 24 percent, some 11 percent occurred at medical facilities and about 13 percent occurred at research, educational and other facilities (table 10-13) *(10.9)*.

The overexposures ranged from a 1.26 rem whole body exposure to a 30,000 rem extremity exposure. Only 48 (17 percent) of the total number of overexposures to external radiation exceeded the applicable annual limits and were required to be reported to the Commission within 72 hours (10 CFR 20.403). During the period of 1971-1973, there were six comparable exposures reported by AEC contractors *(10.9)*.

The Atomic Energy Commission also operates a U.S. Transuranium Registry (USTR) which collects information from AEC contractors and licensees regarding employees potentially exposed to transuranium elements. Participation in this registry, which was established in 1968, is completely voluntary on an individual basis and includes release of medical and health physics data. Permission is also obtained on a voluntary basis for post mortem analyses of tissues of interest.

Table 10-9. Summary of annual whole body exposures, 1973 *(10.8)*

Name	Total monitored	Number of exposures recorded (rem)										
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10+
AEC offices	1,686	1,680	3	3	0	0	0	0	0	0	0	0
Contractors	[a]152,431	149,523	1,947	726	172	60	2	1	0	0	0	0
Licensees	67,862	60,841	3,600	2,050	654	358	177	95	49	25	9	4
Total	221,979	212,044	5,550	2,779	826	418	179	96	49	25	9	4

[a] Includes some 62,000 visitors.

Table 10-10. Distribution of annual whole body exposures for covered licensees, 1974 *(10.7)*

Covered Categories of NRC Licensees	Total No. Monitored	Exposure Ranges (Rems)																
		Less Than Measurable	Less Than 0.10	0.10 0.25	0.25 0.50	0.50 0.75	0.75 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12
Power Reactors	62,044	40,140	9,471	3,317	2,230	1,238	929	2,522	1,378	471	226	86	30	6	0	0	0	0	0
Industrial Radiography	8,792	3,849	1,740	939	635	424	323	547	209	74	22	17	5	2	3	0	1	2	0
Fuel Processing & Fabrication	10,921	6,304	1,801	959	772	316	146	275	126	83	60	23	12	16	12	16	0	0	0
Manufacturing & Distribution	3,340	1,513	748	504	144	84	69	125	59	46	17	21	7	1	2	0	0	0	0
TOTALS	85,097	51,806	13,760	5,719	3,781	2,062	1,467	3,469	1,772	674	325	147	54	25	17	16	1	2	0

Table 10-11. Annual whole body exposures, 1968-1974 *(10.7,10.8)*

Calendar year	AEC contractor employees			Covered licensee personnel		
	Total monitored	Percent of exposures < 2 rems	Number & (percent) of exposures over 5 rems	Total monitored	Percent of exposures < 2 rems	Number & (percent) of exposures over 5 rems
1968	106,958	98.4	8 (0.007)	36,836	97.2	178 (0.5)
1969	102,918	98.4	6 (0.006)	31,176	96.5	151 (0.5)
1970	96,661	98.4	8 (0.008)	36,164	96.1	226 (0.6)
1971	94,319	98.7	13 (0.014)	36,311	95.3	238 (0.7)
1972	87,845	98.7	10 (0.011)	44,690	95.7	230 (0.5)
1973	90,311	98.9	3 (0.003)	67,862	95.0	359 (0.5)
1974				85,097	96.4	

Table 10-12. Summary of annual exposures at nuclear power facilities, 1974 *(10.7)*

Year	Number of operating facilities	Total number monitored	Percent of exposures <2 rems
1969	14	6,332	66.6
1970	20	12,042	83.6
1971	23	14,516	90.1
1972	30	21,288	94.3
1973	41	44,795	94.0
1974	53	62,044	96.5

The principal criterion used by USTR to determine inclusion of an individual in the Registry is that the employer provide a routine surveillance program because of a reasonable likelihood that exposure could occur. Most of the USTR activities have been confined to Hanford, Los Alamos, and Rocky Flats *(10.10)*.

Most of the data on occupational exposure to plutonium comes from medical followup data on military personnel who worked with plutonium in 1944-45 at Los Alamos. Hempelmann et al. reported that "to date, none of the medical findings in the group can be attributed definitely to internally deposited plutonium" *(10.11)*. The selected cases shown in table 10-14 represent systemic plutonium burdens ranging from 0.13 to 0.42 Ci, which correspond to annual bone doses of approximately 2 to 6 rad *(10.10)*.

Summary

Occupational and industrial radiation is concerned with the exposure of individuals to a radiation environment during their occupations. The occupations considered are medicine, radiography, nuclear reactors, waste disposal, feed processing, packaging and transport, radar and special weapons. There are approximately 3.76 radiation workers per 1,000 people in the United States, and in 1970 the average annual individual occupational dose was 0.8 mrem/y.

The data indicate that the largest occupational exposures generally are received by waste disposal workers and, to a lesser extent, by industrial radiographers.

Table 10-13. Summary of overexposures to external sources reported to NRC by licensees, 1971-1974 (*10.9*)

Calendar year	Part of body	Total number of overexposures	Licensed activity reporting overexposures				
			Industrial radiography	Power reactor	Manufacturing and distribution	Medical	Other
1971	whole body	45	22 (49%)	2 (4%)	5 (11%)	13 (29%)	3 (7%)
	skin	2	-	-	-	-	2 (100%)
	extremity	13	5 (38%)	-	5 (38%)	-	3 (24%)
1972	whole body	47	18 (38%)	16 (34%)	3 (6%)	-	10 (21%)
	skin	1	-	-	-	-	1 (100%)
	extremity	12	4	-	6 (50%)	-	2 (17%)
1973	whole body	58	23 (40%)	19 (33%)	3 (5%)	9 (15%)	4 (7%)
	skin	2	-	-	-	-	2 (100%)
	extremity	5	1 (20%)	-	2 (40%)	-	2 (40%)
1974	whole body	95	29 (31%)	43 (44%)	8 (8%)	8 (8%)	7 (7%)
	skin	1	-	-	-	-	1 (100%)
	extremity	7	-	-	6 (86%)	1 (14%)	-
Total	whole body	245	92 (38%)	80 (33%)	19 (8%)	30 (12%)	24 (10%)
	skin	6	-	-	-	-	6 (100%)
	extremity	37	10 (27%)	-	19 (51%)	1	7 (19%)

Table 10-14. Plutonium systemic body burden estimates for selected Manhattan project plutonium workers at three different times[a] *(10.10)*

CASE CODE	$^{239-240}Pu$ (nCi) 1953	1962	1972
1	30-60	10	210
3	80	130	420
4	80	140	260
5	80	140	180
6	60	70	140
7	60	80	150
17	40	90	130

[a] PERSONS WITH MORE THAN 120 nCi $^{239-240}Pu$ SYSTEMIC BURDEN IN 1972.

The highest occupational personnel exposures from U.S. operating nuclear power plants for the period 1970-72 have resulted from in-plant maintenance activities. The average individual occupational exposure from PWR's was 1.08 rem/y and from BWR's, it was 1.23 rem/y with a total average of 1.16 rem/y. Table 10-15 provides a statistical breakdown of the whole body occupational population exposures that have occurred in nuclear facilities in 1973, the last year for which comparative data are available.

Table 10-15. Whole body occupational population exposures, 1973

Group	Total personnel monitored	Percent exposures < 2 rems	Exposures greater than 5 rems	
			Number	Percent
AEC contractor employees	90 311	98.9	3	0.003
AEC license personnel	67,862	95.0	359	0.5

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(10.2) UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION. Report to the General Assembly. Ionizing Radiation: Levels and Effects. Volume 1:Levels. United Nations, New York (1972).

(10.3) FEDERAL RADIATION COUNCIL. Radiation protection guidance for federal agencies. Federal Register. (May 18, 1960).

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(10.6) U.S. ATOMIC ENERGY COMMISSION. Additional testimony of Mr. Morton I. Goldman on behalf of the Consolidated Utility Group, Part I Rule-making Hearing on Effluents from Light Water Cooled Nuclear Power Reactors (November 9, 1973).

(10.7) U.S. NUCLEAR REGULATORY COMMISSION. Seventh annual occupational radiation exposure report, 1974, NUREG-75/108. U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Division of Technical Review, Washington, D.C. (November 1975).

(10.8) U.S. ATOMIC ENERGY COMMISSION. Sixth annual report of the operation of the U.S. Atomic Energy Commission's centralized ionizing radiation exposure records and reports system. Prepared by Assistant Director for Workmen's Compensation, Division of Operational Safety, Atomic Energy Commission, Washington, D.C. (September 1974).

(10.9) Personal communication to Floyd L. Galpin, Director, Environmental Analysis Division, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C., from W. G. McDonald, Director, Office of Management Information & Program Control, U.S. Nuclear Regulatory Commission, Washington, D.C. (February 17, 1976).

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Chapter 11 - Consumer Products

Television sets

The Bureau of Radiological Health (BRH) in the Department of Health, Education and Welfare has the responsibility for administrating the Radiation Control for Health and Safety Act. One of the purposes of this act is to protect the U.S. population from unnecessary exposure to radiation from electronic products.

High-voltage rectifier, shunt regulator tubes and the picture tube are the sources of x rays in color television sets. Today the trend is toward solid state circuitry which means that the picture tube will be the only x-ray emitter remaining in television sets within a few years.

In 1968, BRH conducted a survey of color television sets in the Metropolitan Washington, D.C. area. The average rate of emission of ionizing radiation 5 cm from the front face of the sets was found to be 0.043 mR/h *(11.1)*.

If it is assumed that the viewing habits of the population in the survey is typical of the entire U.S. population, that the population exposed will be close to 100 percent in 1980, and that the trend continues in reduction of emission rate from television sets *(11.2)*, a reduction of average emission rate to 0.025 mR/h at 5 cm by 1980 is predicted *(11.3)*. However, according to UNSCEAR,".... under conditions of normal operation and proper servicing, the x-ray emission from recently-built colour television receivers is negligible" *(11.4)*.

Timepieces containing radioactive material

In recent years, the use of radium in the dial painting industry for the illumination of timepieces has been replaced by tritium and, to a lesser extent, promethium-147. The sales of radium-activated watches were estimated to be about 3 million in 1968 in contrast to only a few sales of these watches in the past three years. However, radium continues to be used in clocks (table 11-1).

This trend is reflected in a report published by the Bureau of Radiological Health in July 1975 in which the estimates of population dose for 1973 were 3600 person-rem from 24 million tritium-activated timepieces versus 2500 person-rem from 8.4 million radium-activated timepieces (table 11-2). There was no reliable data on promethium-activated timepieces. These estimates were derived from the average activities per timepiece--5 mCi of tritium for 24 million timepieces and 0.5 μCi of radium for 8.4 million timepieces *(11.5)*. If radium had been used in all of the timepieces, the dose would have been significantly higher. Therefore, with the decrease in the use of radium and the increase in the use of tritium and promethium, the population dose from timepieces should decrease in the future.

Summary

The radiation dose from consumer products is concerned with the doses from television sets and timepieces containing radioactivity. It has been estimated that the average dose rate 5 cm from a color television screen was 0.043 mR/h in 1968 and will be 0.025 mR/h in 1980. The dose rate from a recently-built color set is negligible. It has also been estimated that the population dose from timepieces is 3,600 person-rem/y for timepieces with tritium-activated dials and 2,500 person-rem/y for timepieces with radium-activated dials.

There are known to exist a number of other consumer products which have been identified as potential radiation risks. One of the historically oldest of these is dinnerware contaminated with natural radioactive materials. Of more recent publicity have been false teeth and eyeglasses. Quantitative information on radioactivity in these items and subsequent exposure levels have been difficult to document. However, efforts will be continued to find such information for inclusion in subsequent editions of this report.

Table 11-1. Luminous timepieces distributed in United States *(11.5)*

	1971	1972	1973
Wristwatches			
a) Tritium activated			
Made in U.S.	2,710,000	2,330,000	1,800,000
Imported	5,670,000	6,540,000	3,600,000
b) Promethium activated			
Made in U.S.	Negligible	Negligible	Negligible
Imported	620,000	770,000	900,000
c) Radium-226 activated	Negligible	Negligible	Negligible
Clocks			
a) Tritium activated			
Made in U.S.	18,000	10,000	20,000
Imported	500,000	190,000	240,000
b) Promethium-147 activated			
Made in U.S.	Negligible	Negligible	Negligible
Imported	1,470,000	970,000	1,370,000
c) Radium-226 activated	2,800,000	2,800,000	2,800,000

Table 11-2. Evaluation of population dose in the United States to radioluminous timepieces *(11.5)*

	Tritium	Promethium-147	Radium
Number of timepieces	24×10^6	6×10^6	8.4×10^6
Average activity of timepiece	5 mCi	Unknown	0.5 µCi
Total activity	120 kCi	Unknown	4.2 Ci
Population dose (person-rem/year)	3600	Unknown	2500

References

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(11.2) ELECTRONIC INDUSTRIES ASSOCIATION. Evaluation of television contribution to the annual genetically significant radiation dose of the population. Radiol. Health Data Rep. 12:363-369 (July 1971).

(11.3) U.S. ENVIRONMENTAL PROTECTION AGENCY. Estimates of ionizing radiation doses in the United States, 1960-2000, ORP/CSD 72-1, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C. 20460 (August 1972).

(11.4) UNITED NATIONS. Report of the United Nations Scientific Committee on the effects of Atomic Radiation. Vol. 1, New York (1972).

(11.5) PUBLIC HEALTH SERVICE. Public health implications of radioluminous materials, FDA 76-8001. Bureau of Radiological Health, Rockville, Md. 20852 (July 1975).

Chapter 12 - Health Effects of Ionizing Radiation Exposure

In order to appropriately place the reported ionizing radiation exposures in this report in the proper perspective, some relatedness to potential health effects is desirable. To allow some interpretation in this respect, this section will present a generic evaluation of the various health effect risk factors that can be applied.

No attempt has been made to translate individual exposure values to health effects for several reasons. First, it is recognized that the degree of uncertainty with the doses is not consistent. Although it is intended to report doses based on actual data whenever possible, many of the values still represent estimates with potentially large variability. A second constraint on applying effects conversion factors to the exposure data is the lack of definitive information relative to the population parameters, especially where exposures are reported for specific facilities. This is important as there are differences in sensitivity; for example, children are more radiosensitive than adults. Therefore, while one might apply such risk conversion factors to large population groups where some generalizations as to population parameters are applicable, it is increasingly invalid to apply such generalizations as the population under consideration becomes smaller and more specific. Besides these two prime reasons, others, such as the lack of specific risk conversion factors for many organs and the lack of information on the exact pathway of exposure in many cases, have led to the decision to handle health effects in this general manner, at least for this first report.

In carrying out its activities of environmental radiation assessment and standards setting, it was necessary, in spite of the uncertainties, for EPA to establish a policy for the general way in which it would relate radiation dose and effects. Such a policy was devised and issued on March 3, 1975, and is included here in its entirety.

"EPA Policy Statement on Relationship Between Radiation Dose and Effect

"The actions taken by the Environmental Protection Agency to protect public health and the environment require that the impacts of contaminants in the environment or released into the environment be prudently examined. When these contaminants are radioactive materials and ionizing radiation, the most important impacts are those ultimately affecting human health. Therefore, the Agency believes that the public interest is best served by the Agency providing its best scientific estimates of such impacts in terms of potential ill health.

"To provide such estimates, it is necessary that judgments be made which relate the presence of ionizing radiation or radioactive materials in the environment, i.e., potential exposure, to the intake of radioactive materials in the body, to the absorption of energy from the ionizing radiation of different qualities, and finally to the potential effects on human health. In many situations, the levels of ionizing radiation or radioactive materials in the environment may be measured directly, but the determination of resultant radiation doses to humans and their susceptible tissues is generally derived from pathway and metabolic models and calculations of energy absorbed. It is also necessary to formulate the relationships between radiation dose and effects; relationships derived primarily from human epidemiological studies but also reflective of extensive research utilizing animals and other biological systems.

"Although much is known about radiation dose-effect relationships at high levels of dose, a great deal of uncertainty exists when high level dose-effect relationships are extrapolated to lower levels of dose, particularly when given at low dose rates. These uncertainties in the relationships between dose received and effect produced are recognized to relate, among many factors, to differences in quality and type of radiation, total dose, dose distribution, dose rate, and radiosensitivity, including repair mechanisms, sex, variations in age, organ, and state of health. These factors involve complex mechanisms of interaction among biological, chemical, and physical systems, the study of which is part of the continuing endeavor to acquire new scientific knowledge.

"Because of these many uncertainties, it is necessary to rely upon the considered judgments of experts on the biological effects of ionizing radiation. These findings are well-documented in publications by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the National Academy of Sciences (NAS), the International Commission on Radiological Protection (ICRP), and the National Council on Radiation Protection and Measurements (NCRP), and have been used by the Agency in formulating a policy on relationship between radiation dose and effect.

"It is the present policy of the Environmental Protection Agency to assume a linear, nonthreshold relationship between the magnitude of the radiation dose received at environmental levels of exposure and ill health produced as a means to estimate the potential health impact of actions it takes in developing radiation protection as expressed in criteria, guides, or standards. This policy is adopted in conformity with the generally accepted assumption that there is some potential ill health attributable to any exposure to ionizing radiation and that the magnitude of this potential ill health is directly proportional to the magnitude of the dose received.

"In adopting this general policy, the Agency recognizes the inherent uncertainties that exist in estimating health impact at the low levels of exposure and exposure rates expected to be present in the environment due to human activities, and that at these levels, the actual health impact will not be distinguishable from natural occurrences of ill health, either statistically or in the forms of ill health present. Also, at these very low levels, meaningful epidemiological studies to prove or disprove this relationship are difficult, if not practically impossible, to conduct. However, whenever new information is forthcoming, this policy will be reviewed and updated as necessary.

"It is to be emphasized that this policy has been established for the purpose of estimating the potential human health impact of Agency actions regarding radiation protection, and that such estimates do not necessarily constitute identifiable health consequences. Further, the Agency implementation of this policy to estimate potential human health effects presupposes the premise that, for the same dose, potential radiation effects in other constituents of the biosphere will be no greater. It is generally accepted that such constituents are no more radiosensitive than humans. The Agency believes the policy to be a prudent one.

"In estimating potential health effects, it is important to recognize that the exposures to be usually experienced by the public will be annual doses that are small fractions of natural background radiation to at most a few times this level. Within the United States, the natural background radiation dose equivalent varies geographically between 40 to 300 mrem per year. Over such a relatively small range of dose, any deviations from dose-effect linearity would not be expected to significantly affect actions taken by the Agency, unless a dose-effect threshold exists.

"While the utilization of a linear, nonthreshold relationship is useful as a generally applicable policy for assessment of radiation effects, it is also EPA's policy in specific situations to utilize the best available detailed scientific knowledge in estimating health impact when such information is available for specific types of radiation, conditions of exposure, and recipients of the exposure. In such situations, estimates may or may not be based on the assumptions of linearity and a nonthreshold dose. In any case, the assumptions will be stated explicitly in any EPA radiation protection actions.

"The linear hypothesis by itself precludes the development of acceptable levels of risk based solely on health considerations. Therefore, in establishing radiation protection positions, the Agency will weigh not only the health impact, but also social, economic, and other considerations associated with the activities addressed."

Within the context of this overall policy statement, EPA uses primarily the recommendations of the National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (BEIR) *(12.1)* as expressed in their November 1972 report to arrive at dose to health risk conversion factors. Besides the concept of linearity expressed in the policy statement, it is further assumed that health effects that have been observed at dose rates much greater than those represented in this report are indicative of radiation effects at lower dose rates. Any difference in biological recovery from precarcinogenic radiation damage due to low dose rates is neglected in the BEIR health risk estimates. On the other hand, in some cases, the BEIR risk estimates are based on relatively large doses where cell killing may have influenced the probability of delayed effects being observed and hence, underestimate the effects at low doses. The dose-risk conversion factors that EPA has adopted from the BEIR report are neither upper nor lower estimates of risk, but those that are considered "best estimates."

One must caution against interpreting the product of dose and risk conversion factor as a prediction of actual number of effects to be sought out in the real world. The dose conversion factors (from concentration to dose) and the risk conversion factors (dose to effects) are really representative of a range of values.

For instance, the BEIR Committee has made a determination, based on their evaluation of the increase of the ambient cancer mortality per rem, that ranges from 100 to 450 deaths per million persons per rem during a 30-year followup period. Even though the following discussion will indicate average values that EPA has chosen to use for various dose to health effect conversions, it can be seen that they are likely to be revised as new information becomes available.

Dose-risk Conversion Factors

1. Total body dose-risk

The BEIR Report calculates the excess cancer mortality risk (including leukemia mortality) from whole body radiation by two quite different models. The absolute risk model[1] predicts about 100 cancer deaths per 10^6 person-rem while the relative risk model[2] predicts between 160 and 450. An average cancer mortality of 300 annually per 10^6 person-rem would seem to be an appropriate mean for the relative risk model. The average of the absolute and relative risk models is 200, which is close to the estimates of cancer mortality risk listed as "most likely" by the committee. Cancer mortality is not a measure of the total cancer risk, which the committee states is about twice that of the yearly mortality.

Estimated cancer risk from total body irradiation

Cancer mortality = 200 deaths per year for 10^6 person-rem annual exposure. Total cancers = 400 cancers per year for 1 person-rem annual exposure to the total body.

2. Gonadal dose-risk

The range of the risk estimates for genetic effects set forth in the BEIR report is so large that such risks are better considered on a relative basis for different exposure situations than in terms of absolute numbers. The range of uncertainty for the "doubling dose" (the dose required to double the natural mutation rate) is 10-fold (from 20 to 200 rad); and because of the additional uncertainties in (1) the fraction of presently observed genetic effects due to background radiation, and (2) the fraction of deleterious mutations eliminated per generation, the overall uncertainty is about a factor of 25. The total number of individuals showing genetic effects such as congential anomalies, constitutional and degenerative diseases, etc., is estimated at somewhere between 1,800 and 45,000 per generation per rad of continuous exposure at equilibrium; i.e., 60-1,500 per year if a 30-year generation time is assumed. This equilibrium level of effect will not be reached until after many generations of exposure; the risk to the first generation postexposure is about a factor of 5 less.

The authors of the BEIR report reject the notion of "genetic death" as a measure of radiation risk. Their risk analysis is in terms of early and delayed effects observed post partum and not early abortion, still births or reduced fecundity. Because of the seriousness of some of the genetic effects considered here, e.g., mongolism, the emotional and financial stress would be somewhat similar to death impact. Indeed, 10 percent of the effects described are those which lead directly to infant or childhood mortality (fetal mortality is excluded). For some purposes, this class of genetic effects are considered on the same basis as mortality.

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[1] Absolute risk estimates are based on the reported number of excess cancer deaths per rad that had been observed in exposed population groups, e.g., Hiroshima, Nagasaki, etc.

[2] Relative risk estimates are based on the percentage increase per rem in the ambient cancer mortality.

Estimated serious genetic risk from continuous gonadal irradiation

Total risk = 200 effects per year for 10^6 person-rem annual exposure.

3. Lung dose-risk

Due to the insufficient data for the younger age groups, estimates of lung cancer mortality in the BEIR report are only for that fraction of the population of age 10 or more. For the risk estimate made below, it is assumed that the fractional abundance for lung tumors is the same for those irradiated at less than 10 years of age as it is for those over 10. On an absolute risk basis, lung cancer mortality in a population would be about 18 deaths per annum per 10^6 persons irradiated continuously at a dose rate of 1 rem per year. This is a minimum value. The BEIR report states that the absolute risk estimates may be too low because observation times for exposed persons are still relatively short compared to the long latency period for lung cancer. Furthermore, lung cancer risks calculated on the basis of the geometric mean of the relative risk is 3.4 times larger than the estimated absolute risk. Therefore, an average of mean relative and absolute risk estimates is given in the following dose-risk estimate.

Estimated lung cancer risk from continuous lung irradiation

Excess lung cancer mortality = 40 deaths per year for 10^6 person-rem annual exposure.

4. Skin dose-risk

Epidemiological evidence of any real risk from such insults at the dose levels considered here is nonexistent. This is not to say that the linear dose-effect assumption does not hold for skin cancer but rather that the BEIR Committee found from the extensive evidence they examined that the "numerical estimates of risk at low dose levels would not seem to be warranted."

5. Thyroid dose-risk

Iodine is concentrated in the human thyroid. Therefore, the insult from radioiodines is important only for the thyroid. The dose to other organs is over an order of magnitude less. Two health effects follow high level exposures of thyroid tissue to ionizing radiation: benign neoplasms and thyroid cancer. Though the former is a more common radiation effect, only the risk from cancer is considered here.

While children are particularly sensitive to radiation damage to their thyroid glands, thyroid cancer is not usually a deadly disease for persons in younger age groups but mortality approaches 25 percent in persons well past middle age. It is not presently known if the radiation-induced cancers which are more frequent for persons irradiated early in life will follow the same patterns of late mortality.

The BEIR report provides risk estimates only for morbidity (not mortality) and only for persons under 9 years of age, i.e., 1.6-9.3 cancers per 10^6 person-rem years. From the Hiroshima data and other studies it would appear that, for persons over 20 years old, the radiation-induced thyroid cancer incidence is lower, but not zero as assumed before recent followup data became available.

Since information in the BEIR report is not sufficient in itself to estimate the cancer incidence from continuous exposure, tentative risk estimates for this study are also based on information in other references *(12.2-12.5)* as well as the mean of the BEIR Committee's various estimates of incidence per rem. Infants and fetuses are, of course, the most sensitive group. By weighting the age group sensitivity and using population percentages for the age groups, a population age-weighted value was obtained.

Estimated thyroid cancer risk

Thyroid cancer risk = excess thyroid cancers per 10^6 rems to the thyroid.

It is unlikely that the mortality from thyroid cancer would be more than 10-25 percent of its rate of incidence. As for other radiation effects, a true measure of the risk from thyroid cancers could be life shortening, but insufficient mortality data prevents such an approach.

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Chapter 13 - Nonionizing Electromagnetic Radiation

As its name implies, nonionizing electromagnetic radiation does not produce ionized particles when it is absorbed by the material of interest. Absorbed energy is converted to electronic excitation and to molecular vibration and rotation. The ionization potentials of the principal components of living tissue (water, and atomic oxygen, hydrogen, nitrogen, and carbon) are between 11 and 15 electron volts (eV). Michaelson *(13.1)* considers 12 eV to be the lower limit for ionization in biological systems, while noting that some weak hydrogen bonds in macromolecules may have lower ionization potentials. As a point of reference, an ultraviolet wavelength of 180 nanometers corresponds to an energy of about 7 eV. Thus, for practical purposes, the nonionizing part of the electromagnetic spectrum includes the ultraviolet, visible, infrared, radiofrequency and lower frequency regions including power distribution frequencies at 50 and 60 Hz.

Because of the increase in the number and power of sources in the radiofrequency range since 1940, recent interest has focused on nonionizing electromagnetic radiation at frequencies below 300 GHz or photon energies less than 1.24×10^{-3} eV. The voluntary American National Standards Institute (ANSI) *(13.2)* exposure standard and the OSHA *(13.3)* occupational exposure standard cover the frequency range from 10 MHz to 100 GHz; the Bureau of Radiological Health (BRH) *(13.4)* microwave oven performance standard and the proposed BRH *(13.5)* diathermy performance standard are for frequencies from 890 MHz to 6 GHz and 890 MHz to 22.25 GHz, respectively. Though there may be limited exposure problems associated with the use of lasers and some noncoherent light sources, at the present time we are not aware of manmade sources of nonionizing electromagnetic radiation operating above 300 GHz which would produce significant environmental levels. Therefore, this discussion is restricted to frequencies below 300 GHz.

Description of data base

There are two types of data base which are pertinent to analyzing environmental levels of nonionizing electromagnetic radiation at frequencies below 300 GHz. The first of these consists of computer files of source location and characteristics that permit the calculation of expected exposure levels if an appropriate model is available. This type of analysis has proved more successful in analyzing levels from individual sources than in predicting levels from the superposition of fields from many sources. The second type of data base consists of reports on studies of specific sources and the ambient environment. Until recently, only limited data have been gathered on the general ambient environment.

Sources of data

The Office of Telecommunications Policy (OTP) assigns operating frequencies to government users of the electromagnetic spectrum and the Federal Communications Commission (FCC) assigns frequencies to nongovernment users. The most extensive inventory of sources of nonionizing radiation in the United States is maintained at the Electromagnetic Compatibility Analysis Center (ECAC), Department of Defense, Annapolis, Md. The ECAC Environmental File contains records of government and nongovernment communications-electronics equipment. Information in the records includes the operational characteristics of the equipment, its location, and administrative information, such as who is operating it. There are four subfiles of the Environmental File. These are the E-file, the Interdepartment Radio Advisory Committee (IRAC) File, the FCC file, and the American Telephone and Telegraph Company (AT&T) file. The subfiles are described in the following paragraphs.

E-file

The E-file is primarily composed of deployed military equipment records. The major sources of data for this file are the FAA, the Department of Defense, the National Aeronautics and Space Administration, and the U.S. Coast Guard. ECAC personnel review the incoming data, resolve discrepancies, and perform maintenance of the file daily. The utility of this file is dependent on the currency and accuracy of the information supplied by the various agencies.

IRAC file

IRAC is an advisory committee consisting of government agency representatives to the Office of Telecommunications Policy. The IRAC file is maintained for the Interdepartment Radio Advisory Committee by the Office of Telecommunications, Department of Commerce. The file includes frequency authorizations of all U.S. government agencies and is the only authoritative record of the total U.S. government use of the radiospectrum, including the equipment used.

AT&T file

AT&T file information is obtained directly from the American Telephone and Telegraph Company and represents their common carrier microwave equipments. The file contains data on locations, frequency, latitude, longitude, power fixed antenna bearing, and antenna gain for each transmitter. The data are maintained by AT&T and supplied to ECAC semiannually.

FCC file

ECAC gets data for the FCC file from the National Technical Information Service on a semiannual basis. The data supplied represent all FCC-licensed entries except in the Amateur Bands, Citizens Band, Aircraft and Ship Services. Equipment information in this file is limited.

The source information in the ECAC data base is supplemented or complimented by source listings from the FCC for specific broadcast services such as FM radio or VHF television. Other complimentary sources of information include the Broadcasting Yearbooks published by Broadcasting Publications, Washington, D.C. and the Television Factbook published by Television Digest, Inc., Washington, D.C.

There are a large number of low power devices which are not included in the source inventories cited above; at least 459,000 land mobile records are not included. It is estimated that about 2,000,000 microwave ovens will be in service by the end of 1975 *(13.6)*. In addition, there are large but undetermined numbers of noncommunications, industrial, and medical sources such as industrial dryers and medical diathermy units. These low power or high power contained sources are not expected to make a large contribution to ambient environmental levels, especially at distances far from the source. Control of exposure to radiation from these sources is currently accomplished by limiting power (FCC), through product performance standards (BRH), and occupational exposure standards (OSHA).

Specific source environments

In February 1975, the Electromagnetic Radiation Management Advisory Council (ERMAC), an advisory group to OTP in the area of "side effects" from use of the spectrum hosted a Work Session on "Measurement of Environmental Levels of Nonionizing Electromagnetic Radiation." Some of the information in this and the following section is condensed from the Work Session summary report *(13.7)*. A large amount of data has been gathered on the radiation levels produced by specific sources. The FCC is conducting a limited study of fields encountered in the immediate environs of radar and television facilities. The National Bureau of Standards is surveying emissions from Federal Aviation Administration systems including localizer arrays, air traffic control radars, and weather radars in aircraft. The National Institutes of Occupational Safety and Health is conducting measurements of both E and H fields in the industrial, scientific, and medical (ISM) bands between 13 and 40 MHz as part of its industrial safety and research effort and in support of OSHA.

In the Department of Defense, measurements programs are carried out by the Air Force, Army, and Navy. The responsibility for monitoring radiofrequency radiation emissions from Air Force systems is shared by the Air Force Communications Service, Air Force Radiological Health Laboratory, base level support groups, and for some special problems, the USAF School of Aerospace Medicine. All operational Air Force emitters are periodically surveyed to maintain appropriate exclusion or controlled areas for personnel safety and to minimize risks from interaction with electro-explosive devices and fuels. Recent surveys have been conducted to establish "low- and high-risk" exclusion radii for cardiac pacemaker interference.

The responsibility for monitoring Army systems rests with the Laser Microwave Division, U.S. Army Environmental Hygiene Agency. Comprehensive surveys at all Army installations and activities are conducted every 3 years. This effort is currently averaging over 100 reports per year, representing 25-35 installations. In addition, all radiofrequency devices in the Army's research, development, testing and evaluation cycle are evaluated.

The Navy has a measurement program which is part of the Shipboard Electromagnetic Compatibility Improvement Program. Class evaluations are being performed to reveal the electromagnetic status of naval vessels. Several analytical models have been developed to predict fields on ships and the results compared to measurements. Measurements have also been made at Navy shore activities.

The Environmental Protection Agency is conducting studies to determine the need for setting standards for exposure to environmental nonionizing radiation. EPA has measured the radiation levels from a number of specific source types. These include satellite communication systems, acquisition and tracking radars, air traffic control radars, weather radars, and UHF-television transmitters. An analytical model for predicting levels from sources using parabolic antennas has been developed and compared to other methods and measured data. Electric field profiles for 345-, 500-, and 765-kV overhead power transmission lines have been determined.

Ambient environmental levels

For the purposes of this discussion, we will broadly define the general ambient electromagnetic environment to be the electromagnetic field in the frequency band from 0 to 300 GHz. It results from the superposition of the field from all sources contributing to the field at the point of interest. In practice this means all sources which produce fields greater than the noise level of the detection system will contribute to the measured level. The actual level may be high or low depending on the distribution of contributing sources, but in most cases, should be relatively low when compared to levels in the main beam of powerful sources. Actual measurements will, for the most part, cover more restricted frequency ranges than that considered in the definition. Two types of instruments are used, those which preserve frequency information and those which integrate across a band of frequencies. Only a limited amount of data is available on general ambient environments. A great deal of data has been collected in so-called noise studies such as that of Toler *(13.8)*. However, these studies ignore intentional signals and, while they are useful in determining signal amplitude requirements for communication and serve as an indicator of the increase in the use of the electromagnetic spectrum, they are not useful in estimating total exposure.

In 1969, White Electromagnetics and the Public Health Service measured peak power densities in the Washington, D.C. area *(13.9,13.10)*. Radiation levels were monitored over the frequency range from 20 Hz to 10 GHz at 10 sites within a 25-mile radius of the city. The highest levels measured (approximately 10 $\mu W/cm^2$) originated primarily from AM broadcast towers and airport radar installations. The accuracy of the measurements was estimated to be within 15 decibels (dB) in the first paper and at ± 10 dB in the second (dB is a logarithmic unit of power and 10 dB corresponds to one order of magnitude, i.e., a factor of 10). A similar study over a more restricted frequency range was conducted in Las Vegas in 1970 by Envall, Peterson, and Stewart *(13.11)*. The maximum observed power density over the frequency range from 54 to 220 MHz was 0.8 $\mu W/cm^2$. Ruggera *(13.12)* studied the changes in electric field strengths within a hospital before and after the installation of a new transmitting tower 3,200 feet from the hospital. Measurements were made in the frequency range from 54 MHz to 656 MHz and the maximum total rms field strength was about 2 V/m which corresponds to a far-field power density of about 1 $\mu W/cm^2$. A preliminary analysis of the results of a recent study of environmental levels in Boston, Mass., for the frequency range from 54 to 890 MHz indicates that ambient levels were less than 2 $\mu W/cm^2$, and for most sites were in the range from 0.1 to 0.5 $\mu W/cm^2$ *(13.13)*. Whether the range of values reported in these studies is typical of urban environments remains to be determined.

Status of data base analysis

Several analyses have been made of the source data and specific source environments. However, the data base for ambient environmental levels is still too small to permit analyses.

Analysis of source data

A partial inventory of microwave towers, broadcasting transmitters, and fixed radars based on the ECAC data base was jointly published by the Department of Defense and the Department of Health, Education, and Welfare *(13.14)*. The data base has also been used to establish the distribution of transmitters within a 50-mile radius of Washington, D.C. *(13.15)*, the number and location of continuous wave sources with effective radiated powers above 1 megawatt and the number and location of pulsed sources with effective radiated peak powers greater than 1 gigawatt *(13.16)*, and the number of sources capable of producing 0.01, 0.1, 1, and 10 mW/cm^2 at various distances from the source *(13.17)*. These studies give inventories of source capabilities but overestimates the potential for exposure since the main beam of many of these sources is not accessible to people.

Source distributions for a number of other cities have been provided to the Environmental Protection Agency as an aid to selecting sites for making environmental measurements. These distributions were provided as computer printouts and not as published reports.

In 1971, there were 223 continuous wave emitters with an average effective radiated power (ERP) of one megawatt or greater and 375 pulsed emitters with a peak ERP of 10 gigawatts or greater. A one megawatt ERP source can produce a power density of 1 mW/cm^2 at a distance of 0.05 mile and 1 μW/cm^2 at about 2 miles from the source. Figures 13-1 through 13-4 show the number of sources capable of producing 0.01, 0.1, 1, and 10 mW/cm^2 at various intervals from the source. The upper and lower limits of the range correspond to the occupational exposure standards in the United States and U.S.S.R., respectively *(13.17)*. The analysis is based on 56,000 transmitters within the United States having an average ERP greater than 10 watts. The source inventory includes deployed military equipment, frequency authorizations of all U.S. Government agencies, common carrier microwave equipment, and all FCC-licensed equipment except that in the Amateur Bands, Citizens Band, Aircraft and Ships Services and 459,000 land mobile records. From the figures, it can be seen that there are 2,366, 5,099, 16,174, and 30,102 sources which are capable of producing 10, 1, 0.1, 0.01 mW/cm^2, respectively, at distances between 32 and 100 meters in the main lobe of the radiated beam.

Source distribution data such as that available from ECAC has the potential for use in model studies for predicting environmental levels. However, extensive modeling studies should await the development and application of measuring systems that can be used to verify the validity of the models.

Analysis of specific source environments

Techniques and instrumentation are available for the analysis of the fields from most high power sources. Methods for calculating power densities have been given by Mumford *(13.19)* and Tell *(13.20)*. Analysis

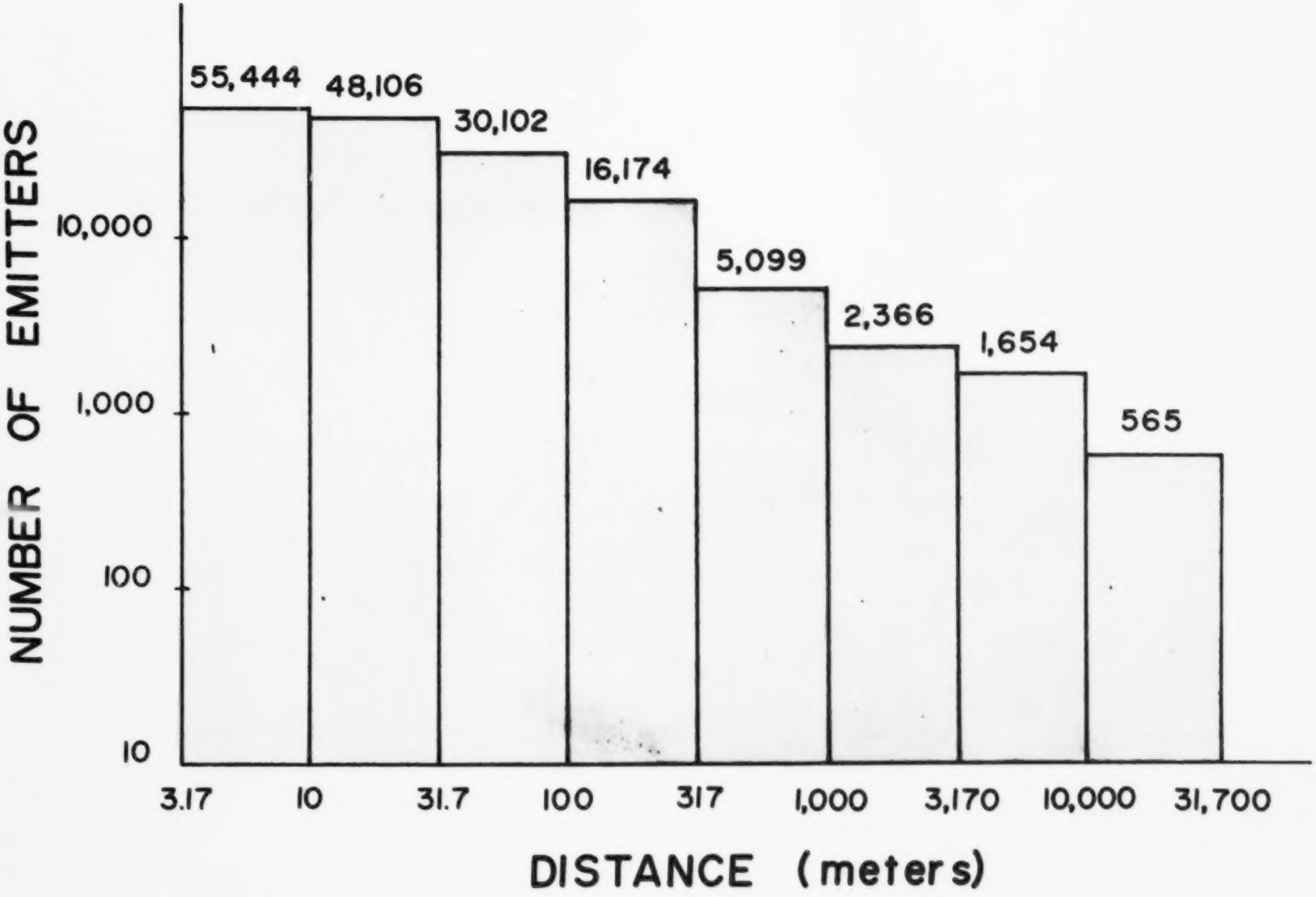

Figure 13-1. Cumulative distribution of emitters in the United States capable of producing an average power density equal to or greater than 0.01 mW/cm^2, as a function of distance *(13.17,13.18)*

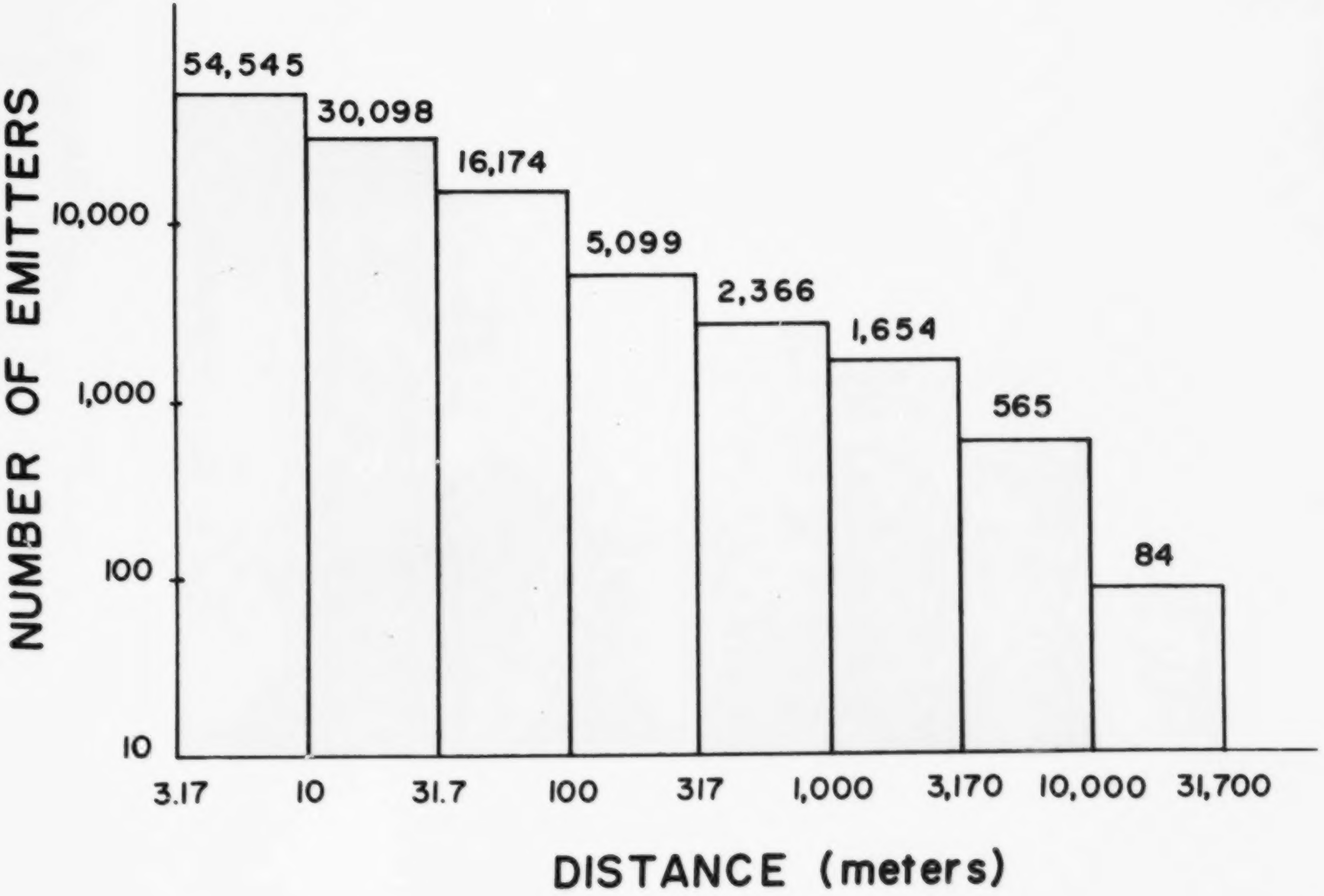

Figure 13-2. Cumulative distribution of emitters in the United States capable of producing an average power density equal to or greater than 0.1 mW/cm^2, as a function of distance *(13.17, 13.18)*

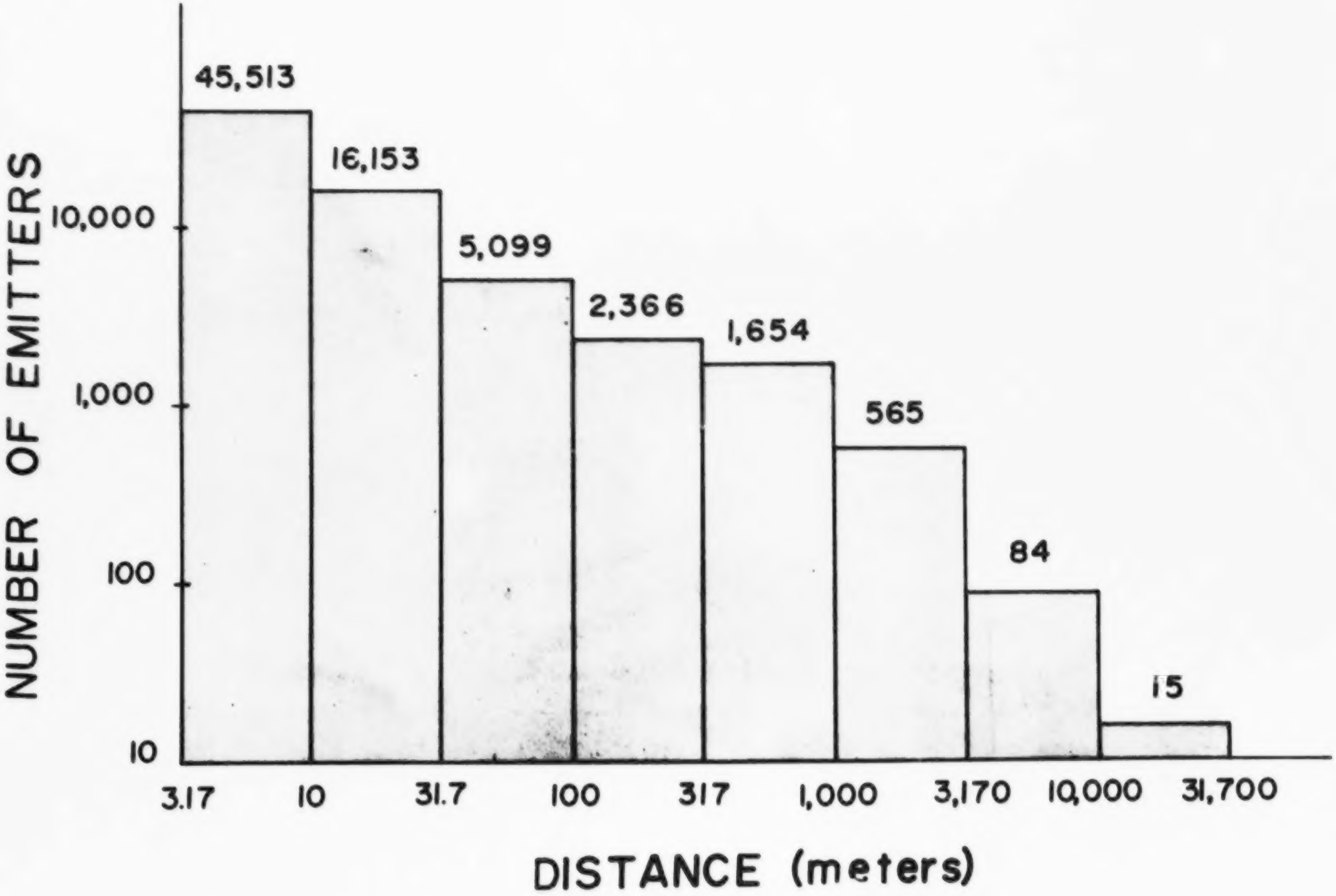

Figure 13-3. Cumulative distribution of emitters in the United States capable of producing an average power density equal to or greater than 1.0 mW/cm^2, as a function of distance *(13.17,13.18)*

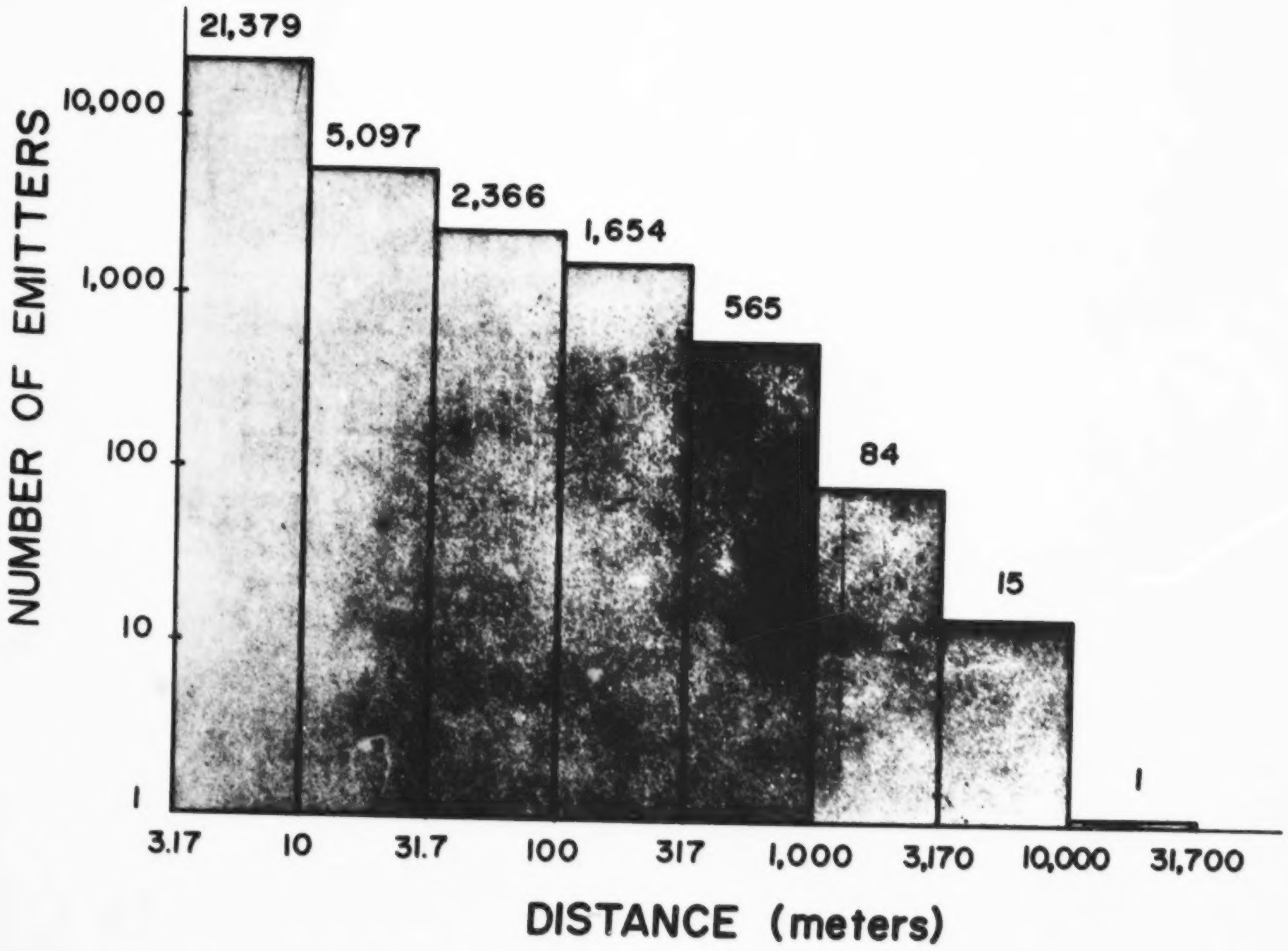

Figure 13-4. Cumulative distribution of emitters in the United States capable of producing an average power density equal to or greater than 10 mW/cm^2, as a function of distance *(13.17,13.18)*

of broadcast radiation sources have been given by Tell *(13.21)*, Tell and Nelson *(13.22)*, and Tell and Janes *(13.23)*. Satellite communications earth terminals have been analyzed by Hankin *(13.24)*. Air traffic control radars radiation levels have been measured by Tell and Nelson *(13.25)* and airborne radars by Tell and Nelson *(13.26)* and Tell, Hankin, and Janes *(13.27)*. The overall impact of high power sources based upon measurements and theoretical analyses has been discussed by Hankin, et al. *(13.28,13.29)*. The highest power sources are satellite communcations stations and large radars. Both of these source classes use very directive antennas to achieve extremely high effective radiated powers. Thus, the probability of being illuminated at any given time by the primary beam of one of these sources is quite small. Many of these sources are remotely located and almost all are surrounded by an exclusion area which further limits the probability of exposure. Site surveys are done for many sources to delineate operational procedures which will prevent the inadvertent exposure of occupied areas. Some sources are mechanically or electrically equipped to limit the pointing directions of antennas or to reduce or shut off power when occupied areas are scanned. The rotational feature of many radars further reduces the exposure levels. Nevertheless, a careful examination of the siting and operation of high powered sources is required to assure they are installed and operated safely. When factors such as number of sources, number of persons potentially exposed, and general operating characteristics and procedures are considered, broadcast transmitters are the most environmentally significant category.

Analysis of ambient environments

As reviewed above, only minimal data are available on the general ambient environment. Very preliminary data in the 55 MHz to 1 GHz frequency range indicate that significant portions of the population are exposed in the 0.1 to 1 $\mu W/cm^2$ range. Whether this is typical of urban exposures remains to be determined from studies now underway. Ambient levels in urban areas are now being measured by EPA with a specially instrumented van. The system has been described by Tell et al. *(13.30,13.31)*. The results of these measurements are to be combined with population data to obtain estimates of population exposure.

Doses from the data base (population exposure estimates)

Because of the complexity of the transmitter environment, the directional properties of antennas, and their operational characteristics, it is difficult to develop any model predictions of exposure fields. Furthermore, the absorption of energy is dependent on frequency, polarization, wave form of the incident wave, and the dielectric constant, size, and shape (radius of curvature) of the irradiated object, so that dose is even more difficult to calculate than exposure. In the area of nonionizing radiation exposure-rate (W/m^2) and dose-rate (W/kg) are probably more meaningful terms than the terms exposure and dose from the ionizing radiation field since they are more closely related to thermoregulation.

An attempt to calculate population exposure-rate to fields in the AM broadcast band (0.54-1.6 MHz) has been made by Athey, Tell, and Janes *(13.32)*. Using a simple propagation model and 1970 census data they calculated the number of people in the Baltimore-Washington area exposed to field strengths over 0.5, 1, and 2 volts/meter. These calculations were later extended to the entire United States *(13.33)*. The results of the calculation indicate that about 0.2 percent (about 440,000 people) of the U.S. population might be exposed to fields greater than 2 volts/meter (1 $\mu W/cm^2$), but exposures greater than 10 volts/meter (26 $\mu W/cm^2$) are minimal in this frequency range. Similar calculations for UHF-TV (470-890 MHz) indicate that perhaps 1 percent (about 2 million) of the U.S. population might be exposed to fields greater than 2 V/m in this frequency range *(13.32)*. Preliminary measurements of environmental data for a single metropolitan area suggests that these estimates may be of the right order of magnitude.

Conclusions and recommendations

Research is now underway in this country and elsewhere to determine and assess any possible biological effect of long-term exposure to low levels of nonionizing radiation and to examine the validity of the present occupational exposure standard of 10 mW/cm^2. Also of concern are the effects of high peak power, low average power, pulsed radiation and the questions of the need for and how to develop standards for the frequency range below 10 MHz where there is currently no exposure standard. Four types of overlapping exposure can be distinguished: (1) exposure in the general environment to intentional signals from the broadcast services, radars, leakage radiation, and other sources, (2) occupational exposures, (3) exposure to leakage radiation from consumer devices such as microwave ovens, and (4) intentional medical exposures. Occupational exposure is subject to control by OSHA. Intentional medical exposure is given at the discretion of a physician. It has been suggested that medical devices conform to the same performance standard for leakage as is now required for microwave ovens by the Food and Drug Administration. There is no direct control of environmental exposures. Indirect controls of environmental exposures are the limitation put on effective radiated power by the FCC, their requirement for posting areas about domestic satellite stations where levels exceed 10 $\mu W/cm^2$, and the operational procedures employed in using both government and nongovernment sources. Also, any telecommunications system planned for purchase by the government, as a condition for spectrum approval, is reviewed by IRAC-OTP to assess among other factors whether levels in excess of 10 $\mu W/cm^2$ will occur and whether operational measures have been provided to insure that people are not exposed above this level.

Two types of environmental exposure can be distinguished. One is the relatively high radiation level from high power sources such as some radars and satellite communications stations where the power density in the useful beam can exceed that thought to be safe for human occupancy even outside the boundary of the facility. The problems associated with such sources are recognized and instrumentation and techniques for analyzing exposure from them are available. The other type of environmental exposure arises from the superposition of the fields from many sources at different frequencies. This exposure may be high or low depending on the location and types of sources contributing to the exposure and includes the specific source problem as a special case. Very little data are available for interpretation at the present time. The required data will become available within the next 18 to 24 months as EPA carries out its ambient level monitoring program in a number of urban areas thoughout the country. Nonionizing environmental radiation data are needed to interpret the results of current biological effects research and establish the predominant frequencies in the environment so that future research for the validation of standards can be appropriately directed.

Summary

In this report, nonionizing electromagnetic radiation is concerned with the radiation intensity in the electromagnetic field resulting from equipment operating in the frequency range up to 300 GHz. This includes equipment generating ultraviolet light, visible light, infrared radiation, radiofrequency and power distribution. Four categories of exposures can be distinguished. These are (1) exposure to signals from broadcasting, radar and power transmission, (2) occupational exposures, (3) exposure to leakage radiation from consumer devices such as microwave ovens, and (4) medical diathermy exposure.

The highest power sources are satellite communication stations and large radio transmitters which generally are located in remote areas and are surrounded by an exclusion area which limits the probability of personnel exposure. The rotational aspect of radar equipment further reduces the chances of prolonged exposure. After consideration of such data as operating characteristics and population density, it appears that broadcast transmitters are the most environmentally significant equipment and that a major portion of the population is exposed to intensities of 0.1 to 1 $\mu W/cm^2$ from this source and 440,000 people in the U.S. population (0.2 percent) are exposed to intensities greater than 1 $\mu W/cm^2$.

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Glossary

Absorbed dose - The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad equals 100 ergs per gram (See rad).

Accelerator - A device for increasing the velocity and energy of charged elementary particles, for example, electrons or protons, through application of electrical and/or magnetic forces.

AEC - U.S. Atomic Energy Commission - In 1975, the Atomic Energy Commission was divided into two new agencies. The regulatory portion became the Nuclear Regulatory Commission, and the reactor development portion became part of the Energy Research and Development Administration.

Body burden - The amount of radioactive material present in the body of a man or an animal.

Boiling water reactor (BWR) - A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine.

By-product material - Any radioactive material (except source material or fissionable material) obtained during the production or use of source material or fissionable material. It includes fission products and many other radioisotopes produced in nuclear reactors.

Cosmic radiation - Radiation of many sorts but mostly atomic nuclei (protons) with very high energies, originating outside the earth's atmosphere. Cosmic radiation is part of the natural background radiation. Some cosmic rays are more energetic than any manmade forms of radiation.

Curie (Ci) - The special unit of activity. One curie equals 3.7×10^{10} nuclear transformations per second.

Daughter - A nuclide formed by the radioactive decay of another nuclide, which in this context is called the parent.

Diathermy - The generation of heat in tissues for medical or surgical purposes by electric currents.

Dose - A general form denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. If unqualified, it refers to absorbed dose.

Dose equivalent (DE) - A quantity used in radiation protection. It expresses all radiations on a common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in rads and certain modifying factors (The unit of dose equivalent is the rem).

Dose rate - Absorbed dose delivered per unit time.

$8.00 reserves - Ore that can be mined and produced at $8.00 a pound.

Electron volt (eV) - A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. Larger multiple units of the electron volt are frequently used: KeV for thousand or kilo electron volts: MeV for million or mega electron volts (1 eV = 1.6×10^{-12} erg).

Energy Research and Development Administration (ERDA) - In 1975, the Atomic Energy Commission was divided into two new agencies. The regulatory portion became the Nuclear Regulatory Commission and the reactor development portion became part of the Energy Research and Development Administration.

Exposure - A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

External radiation - Radiation from a source outside the body - the radiation must penetrate the skin.

Flux (neutron) - A term used to express the intensity of neutron radiation. The number of neutrons passing through a unit area in unit time. For neutrons of given energy, the product of neutron density with speed.

Frequency - Number of cycles, revolutions, or vibrations completed in a unit of time (See hertz).

Genetically significant dose (GSD) - The gonadal dose which, if received by every member of the population, would be expected to produce the same total genetic effect on the population as the sum of the individual doses that are actually received. It is not a forecast of predictable adverse effects on any individual person or his/her unborn children.

Gonad - A gamete-producing organ in animals; testis or ovary.

Half-life - Time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

Hertz - Unit of frequency equal to one cycle per second.

High temperature gas-cooled reactor (HTGR) - A reactor in which the temperature is great enough to permit generation of mechanical power at good efficiency using gas as the coolant.

Internal radiation - Radiation from a source within the body (as a result of deposition of radionuclides in body tissues).

Ionization - The process by which a neutral atom or molecule acquires a positive or negative charge.

Isotopes - Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore, in the mass number. Almost identical chemical properties exist between isotopes of a particular element. The term should not be used as a synonym for nuclide.

Linear accelerators - A device for accelerating charged particles. It employs alternate electrodes and gaps arranged in a straight line, so proportioned that when potentials are varied in the proper amplitude and frequency, particles passing through the waveguide receive successive increments of energy.

Man-rems - The product of the average individual dose in a population times the number of individuals in the population. Syn: person-rems.

Maximum permissible dose equivalent (MPD) - The greatest dose equivalent that a person or specified part thereof shall be allowed to receive in a given period of time.

Millfeed - The ore and other material introduced into the milling process.

Millirem (mrem) - A submultiple of the rem, equal to one-thousandth of a rem (See rem).

Muon - An elementary particle classed as a lepton, with 207 times the mass of an electron. It may have a single positive or negative charge.

NRC - U.S. Nuclear Regulatory Commission: In 1975, the Atomic Energy Commission was divided into two new agencies. The regulatory portion became the Nuclear Regulatory Commission and the reactor development portion became part of the Energy Research and Development Administration.

Nuclide - A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N) and energy content; or alternatively, by the atomic number (Z), mass number A = (N + Z), and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time. Thus, nuclear isomers are separate nuclides, whereas promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered.

Permissible dose - The dose of radiation which may be received by an individual within a specified period with expectation of no significantly harmful result.

Person-rems - The product of the average individual dose in a population times the number of individuals in the population. Syn: man-rems.

Polarization - In electromagnetic waves, refers to the direction of the electric field vector.

Population dose - The sum of radiation doses of individuals and is expressed in units of person-rem (e.g. if 1,000 people each received a radiation dose of 1 rem, their population dose would be 1,000 person-rem).

Power density - The intensity of electromagnetic radiation power per unit area expressed as watts/cm^2.

Pressurized water reactor (PWR) - A power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to achieve high temperature without boiling in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.

Quality factor (QF) - The linear-energy-transfer-dependent factor by which absorbed doses are multiplied to obtain (for radiation protection purposes) a quantity that expresses-on a common scale for all ionizing radiations-the effectiveness of the absorbed dose.

Rad (Acronyn for radiation absorbed dose) - The basic unit of absorbed dose of ionizing radiation. A dose of one rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material (See absorbed dose).

Radioactive decay - Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.

Rem - A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor and any other necessary modifying factors.

Roentgen (R) - The special unit of exposure. One roentgen equals 2.58 x 10^{-4} coulomb per kilogram of air (See exposure).

Skin dose (Radiology) - Absorbed dose at center of irradiation field on skin. It is the sum of the dose in air and scatter from body parts.

Skyshine - Radiation emitted through the roof of the shield (or unshielded roof) that scatters back to ground level due to its deviation by the atmosphere.

Source material - In atomic energy law, any material except special nuclear material, which contains 0.05 percent or more of uranium, thorium, or any combination of the two.

Special nuclear material - In atomic energy law, this term refers to plutonium-239, uranium-233, uranium containing more than the natural abundance of uranium-235, or any material artificially enriched in any of these substances.

Technologically enhanced natural radioactivity (TENR) - Naturally radioactive nuclides whose relationship to the location of persons has been altered through man's activities such as by the activities of mining, tunneling, development of underground caverns, development of wells, and travel in space or at high altitudes.

Terrestrial radiation - Radiation emitted by naturally occuring radionuclides such as potassium-40; the natural decay chains uranium-238, uranium-235, or thorium-232; or from cosmic-ray induced radionuclides in the soil.

Type A and Type B quantities - Legally established maximum amounts of radioactive materials which can be contained in Type A and Type B packages, respectively. Precise definitions are listed in 49 CFR 173.389(1), however, basically the radionuclides are divided into seven groups according to their radiotoxicity and relative potential hazard in transportation. Each of these groups then has a maximum amount assigned depending on the type of package to be used to ship it.

Type A packaging - Containers designed to maintain their integrity, i.e., not allow any radioactive material to be released and to keep the shielding properties intact, under normal transportation conditions. The test conditions which must be met are defined in 49 CFR 173.398b and include heat, cold, reduced air pressure, vibration, water spray endurance, free drop, penetration, and compression standards.

Type B packaging - Containers designed to meet the standards established for hypothetical transportation accident conditions, as well as meeting the Type A packaging standards, without reducing the effectiveness of the shielding or allowing releases in excess of those enumerated in 49 CFR 173.398c(1). The standards to be met by Type B packages, in addition to the Type A standards, are defined in 49 CFR 173.398c(2) and include puncture, thermal, water immersion, and higher free drop tests.

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation.

Volt (V) - The unit of electromotive force (1 volt = 1 watt/1 ampere).

Whole body dose - The radiation dose to the entire body.

International numerical multiple and submultiple prefixes

Multiples and submultiples	Prefixes	Symbols
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

ENVIRONMENTAL RADIATION AMBIENT MONITORING SYSTEM (ERAMS)

The ambient monitoring system known as ERAMS was established in 1973 by the U. S. Environmental Protection Agency's Office of Radiation Programs (ORP). The ERAMS is comprised of nationwide sampling stations which provide air, water and milk samples from which environmental radiation levels are derived.

These sampling locations are selected to provide the best possible combination of radiation source monitoring (such as surface water downstream from a nuclear power reactor) and wide population coverage.

The radiation analyses performed on these samples include general trend indicators, such as gross alpha and gross beta levels, as well as specific analyses for uranium fuel cycle related radionuclides. The latter category includes but is not limited to uranium, plutonium, iodine, and krypton, which are released into the environment from stationary sources such as nuclear power reactors, fuel reprocessing plants and the like.

The data procured from the ERAMS is analyzed to provide environmental surveillance information pertaining to environmental radiation levels and concomitant population exposure. Fluctuations and trends in environmental radiation levels are determined also.

SECTION I. Air Program

Airborne Particulates and Precipitation

Airborne particulates are collected continuously on filters at 21 field stations. These filters are changed one or two times a week and measured for gross beta activity with a G-M survey meter at five hours after collection to allow most of the radon daughters to decay. Another measurement is made at 29 hours when most of the thoron daughter products will have decayed. All field estimates are reported to appropriate EPA officials by mail or telephone depending on the activity levels found. For purposes of summarization, the field estimates are not given in the tables which follow.

The filters are then sent to EERF for more sensitive analyses in a low background beta counter. Gamma scans are performed on all filters showing laboratory gross beta activity greater than 1 pCi/m^3.

Precipitation samples are also collected at the same 21 field stations. These samples are sent to EERF for gross beta activity measurements and gamma scans when the gross beta activity is greater than 10 pCi/l. Tritium measurements are performed on monthly composites from each station. Plutonium-238, -239, and uranium-234, -235 and -238 analyses are performed annually on precipitation samples collected during the spring quarter. Results of these analyses for FY75 are presented in Table A-1.

Table A-2 presents the gross beta activities for airborne particulates for FY75. A compilation of daily measurements is available from the Eastern Environmental Radiation Facility, Montgomery, Alabama 36109.

The monthly analyses for tritium in precipitation samples at the selected stations are shown in Table A-3.

Table A-1

Plutonium and Uranium Analyses
of
Selected Precipitation Composite Samples
March 1975 - May 1975

Location	Plutonium (pCi/l)	Uranium (pCi/l)
AL:Montgomery	238Pu 0	234U 0.013 ± .006
	239Pu 0.004 ± .004	235U 0.004 ± .003
		238U 0.006 ± .004
CA:Berkeley	238Pu 0	234U 0.008 ± .005
	239Pu 0.008 ± .005	235U 0.002 ± .003
		238U 0.009 ± .005
Los Angeles	238Pu 0.005 ± .004	234U 0.014 ± .007
	239Pu 0.017 ± .006	235U 0.001 ± .002
		238U 0.008 ± .005
CO:Denver	238Pu 0.016 ± .008	234U 0.067 ± .018
	239Pu 0.033 ± .012	235U 0.008 ± .005
		238U 0.041 ± .014
ID:Idaho Falls	238Pu 0.036 ± .016	234U 0.042 ± .013
	239Pu 0.111 ± .029	235U 0.011 ± .006
		238U 0.041 ± .013
IL:Chicago	TI	
ND:Bismarck	238Pu 0	234U 0.012 ± .006
	239Pu 0.009 ± .005	235U 0
		238U 0.007 ± .004
NM:Santa Fe	TI	
NV:Las Vegas	238Pu 0.005 ± .004	234U 0.091 ± .020
	239Pu 0.024 ± .008	235U 0.009 ± .005
		238U 0.057 ± .015
NY:Buffalo	238Pu 0.004 ± .004	234U 0.005 ± .003
	239Pu 0.011 ± .006	235U 0.003 ± .003
		238U 0.004 ± .003

Table A-1 (Continued)

Location	Plutonium (pCi/l)	Uranium (pCi/l)
New York	TI	
OH:Columbus	TI	
OK:Oklahoma City	TI	
OR:Portland	238Pu 0	234U 0.027 ± .010
	239Pu 0.007 ± .005	235U 0.004 ± .004
		238U 0.007 ± .005
PA:Harrisburg	238Pu 0.002 ± .003	234U 0.013 ± .006
	239Pu 0.010 ± .006	235U 0.002 ± .002
		238U 0.004 ± .003
Pittsburgh	238Pu 0	234U 0.016 ± .009
	239Pu 0.019 ± .010	235U 0.002 ± .003
		238U 0.016 ± .009
SC:Anderson	238Pu 0.004 ± .004	234U 0.013 ± .006
	239Pu 0.010 ± .005	235U 0.002 ± .002
		238U 0.010 ± .005
Columbia	238Pu 0.001 ± .002	234U 0.011 ± .006
	239Pu 0.008 ± .005	235U 0.001 ± .002
		238U 0.008 ± .005
TN:Knoxville	TI	
VA:Lynchburg	238Pu 0	234U 0.022 ± .008
	239Pu 0.006 ± .004	235U 0.005 ± .004
		238U 0.008 ± .005
NETWORK AVERAGES	238Pu .005	234U .025
	239Pu .020	235U .004
		238U .016

TI - Temporarily Inoperable.

Table A-2

Gross Beta Radioactivity in Air Filters

(pCi/m^3)

July 1974 - June 1975

	EERF LAB MEASUREMENTS		
Location	No. of Samples	Max	Avg
AL:Montgomery	112	.58	.081
CA:Berkeley	103	.30	.054
Los Angeles	106	1.00	.094
CO:Denver	108	.32	.115
FL:Miami	125	.55	.070
ID:Idaho Falls	104	.27	.084
IL:Chicago	3	.20	.180
ND:Bismarck	103	.23	.067
NM:Santa Fe	16	.55	.083
NV:Las Vegas	106	.28	.098
NY:Buffalo	103	.23	.080
New York	28	1.31	.118
OH:Columbus	62	.59	.099
OK:Oklahoma City	94	.25	.092
OR:Portland	96	.15	.049
PA:Harrisburg	126	1.04	.072
Pittsburgh	58	.17	.061
SC:Anderson	24	.16	.078
Columbia	108	.31	.090
VA:Lynchburg	104	.30	.075
NETWORK SUMMARY	1689	1.31	.087

Note: Knoxville, Tenn. station temporarily inoperable.

Table A-3

Tritium Concentration in Precipitation

(nCi/l)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Montgomery	12	.5	.092
CA:Berkeley	8	.15	.019
Los Angeles	6	.3	.055
CO:Denver	11	.5	.30
FL:Miami	0		
ID:Idaho Falls	7	.5	.30
IL:Chicago	0		
ND:Bismarck	12	.4	.25
NM:Santa Fe	0		
NV:Las Vegas	5	.3	.10
NY:Buffalo	12	.5	.241
New York	2	.3	.15
OH:Columbus	0		
OK:Oklahoma City	0		
OR:Portland	12	.3	.072
PA:Harrisburg	10	.5	.21
Pittsburgh	5	.3	.18
SC:Anderson	9	.4	.189
Columbia	12	.8	.369
TN:Knoxville	1	.0	.0
VA:Lynchburg	10	.2	.065
NETWORK SUMMARY	134	.8	.18

Krypton-85 in Air

Krypton-85 is a long-lived noble gas with a half life of 10.8 years. It is released into the atmosphere by nuclear reactor operations, fuel reprocessing, and nuclear detonations. Krypton-85 also occurs naturally in minor quantities primarily from the neutron capture of stable krypton-84 as well as spontaneous fission and neutron-induced fission of uranium. Monitoring of krypton-85 in the atmosphere is being conducted to identify and establish baseline levels and long-term trends.

Dry compressed air samples are purchased from commercial air suppliers semiannually and shipped to the EERF where the krypton-85 is cryogenically separated and counted in a liquid scintiallation system.

Krypton-85 analysis began in January 1973 with sample collections and analyses being performed for 12 sampling locations. These locations were selected to provide atmospheric coverage of the United States with considerations being given to the proximity to fuel reprocessing plants, nuclear reactors, and wide geographic coverage. Results of analyses for krypton-85 in air for the period July 1974 to December 1974 are shown in Table A-4.

Table A-4

Krypton-85 in Air

(pCi/m^3 at STP)

July 1974 - December 1974

Location	Krypton-85 Conc.
AL:Montgomery	18.2
CA:Oakland	NS
FL:Tampa	NS
IL:Chicago	NS
MA:Boston	NS
MI:Detroit	16.7
NC:Greensboro	17.1
NJ:Camden	NS
NY:Buffalo	15.8
Utica	16.8
OK:Oklahoma City	NS
OR:Portland	17.1
NETWORK AVERAGE	17.0

NS, no sample.

Plutonium and Uranium in Airborne Particulates

Plutonium and uranium analyses are performed on quarterly composite samples of the air filters collected from the 21 continuously operating Airborne Particulate and Precipitation sampling sites. Plutonium-238, -239, uranium-234, -235, and -238 are determined by alpha spectroscopy following chemical treatment of the samples. The volume of the air sampled ranges between 25,000 and 40,000 m^3 for each quarterly composite sample analyzed.

The plutonium and uranium in airborne particulates data for FY75 are shown in Tables A-5 through A-9.

Table A-5

238 Plutonium in Airborne Particulates

(aCi/m^3)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Montgomery	4	6.0	4.20
CA:Berkeley	4	3.2	2.20
Los Angeles	4	8.9	6.48
CO:Denver	4	4.4	3.33
FL:Miami	2	3.4	2.55
ID:Idaho Falls	4	5.7	4.18
ND:Bismarck	4	4.3	2.85
NM:Santa Fe	1	1.8	1.80
NV:Las Vegas	4	11.2	6.43
NY:Buffalo	4	6.3	3.98
New York City	2	8.6	7.60
OH:Columbus	4	14.1	7.03
OK:Oklahoma City	2	3.6	3.55
OR:Portland	4	4.8	3.10
PA:Harrisburg	4	3.6	1.73
Pittsburgh	4	6.4	4.55
SC:Anderson	2	12.0	6.75
Columbia	4	4.3	3.60
VA:Lynchburg	4	3.3	1.95
NETWORK SUMMARY	65	14.1	4.10

Note: Chicago, Ill. and Knoxville, Tenn. stations were temporarily inoperable.

Table A-6

239 Plutonium in Airborne Particulates

(aCi/m^3)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Montgomery	4	34.4	23.1
CA:Berkeley	4	21.3	16.3
Los Angeles	4	33.4	27.6
CO:Denver	4	57.8	37.5
FL:Miami	2	29.8	26.7
ID:Idaho Falls	4	41.1	29.7
ND:Bismarck	4	28.8	21.0
NM:Santa Fe	1	19.9	19.9
NV:Las Vegas	4	46.6	32.1
NY:Buffalo	4	39.4	28.9
New York City	2	46.2	31.2
OH:Columbus	4	54.8	34.2
OK:Oklahoma City	2	50.1	43.3
OR:Portland	4	22.3	17.8
PA:Harrisburg	4	27.1	19.6
Pittsburgh	4	38.1	23.1
SC:Anderson	2	34.1	23.2
Columbia	4	42.8	25.1
VA:Lynchburg	4	35.8	24.0
NETWORK SUMMARY	65	57.8	26.5

Note: Chicago, Ill. and Knoxville, Tenn; stations were temporarily inoperable.

Table A-7

234 Uranium in Airborne Particulates

(aCi/m^3)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Montgomery	4	29.0	26.1
CA:Berkeley	4	12.2	10.2
Los Angeles	4	71.6	43.7
CO:Denver	4	92.2	82.0
FL:Miami	2	22.8	21.1
ID:Idaho Falls	4	56.2	43.8
ND:Bismarck	4	65.4	54.8
NM:Santa Fe	1	41.6	41.6
NV:Las Vegas	4	197.	163.
NY:Buffalo	4	222.	135.
New York City	2	73.8	56.9
OH:Columbus	4	119.	94.0
OK:Oklahoma City	2	41.8	41.7
OR:Portland	4	31.0	24.2
PA:Harrisburg	4	40.5	35.3
Pittsburgh	4	116.	95.5
SC:Anderson	2	31.8	28.5
Columbia	4	57.2	47.3
VA:Lynchburg	4	1290.	516.
NETWORK SUMMARY	65	1290.	82.1

Note: Chicago, Ill. and Knoxville, Tenn. stations were temporarily inoperable.

Table A-8

235 Uranium in Airborne Particulates

(aCi/m^3)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Montgomery	4	2.5	1.70
CA:Berkeley	4	1.0	.65
Los Angeles	4	13.5	5.03
CO:Denver	4	6.1	4.95
FL:Miami	2	1.9	1.45
ID:Idaho Falls	4	3.9	2.75
ND:Bismarck	4	4.1	3.60
NM:Santa Fe	1	2.5	2.50
NV:Las Vegas	4	8.1	6.73
NY:Buffalo	4	13.2	8.38
New York City	2	4.1	3.15
OH:Columbus	4	9.0	5.20
OK:Oklahoma City	2	2.6	2.60
OR:Portland	4	2.4	1.68
PA:Harrisburg	4	3.2	2.60
Pittsburgh	4	8.9	6.10
SC:Anderson	2	1.9	1.75
Columbia	4	3.6	2.53
VA:Lynchburg	4	54.3	21.9
NETWORK SUMMARY	65	54.3	4.49

Note: Chicago, Ill. and Knoxville, Tenn. stations were temporarily inoperable.

Table A-9

238 Uranium in Airborne Particulates

(aCi/m^3)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Montgomery	4	26.1	24.2
CA:Berkeley	4	11.5	8.75
Los Angeles	4	76.0	42.1
CO:Denver	4	95.3	83.7
FL:Miami	2	21.6	20.8
ID:Idaho Falls	4	55.8	44.0
ND:Bismarck	4	62.2	52.0
NM:Santa Fe	1	40.8	40.8
NV:Las Vegas	4	110.	92.4
NY:Buffalo	4	232.	139.
New York City	2	78.4	59.1
OH:Columbus	4	127.	90.8
OK:Oklahoma City	2	44.0	40.9
OR:Portland	4	34.6	23.5
PA:Harrisburg	4	42.4	33.3
Pittsburgh	4	112.	94.4
SC:Anderson	2	29.9	27.2
Columbia	4	57.0	46.7
VA:Lynchburg	4	46.5	36.8
NETWORK SUMMARY	65	232.	52.7

Note: Chicago, Ill. and Knoxville, Tenn. stations were temporarily inoperable.

SECTION II. Water Program

Surface Water

Surface water monitoring consists of 55 quarterly surface water samples taken downstream from nuclear facilities or at a background station. The location of the sampling sites was based on all nuclear facilities that were operating, being constructed, or planned through 1976. Tritium analyses are performed quarterly. Gamma scans performed annually showed no detectable activity other than ^{40}K.

The tritium concentrations for the surface water samples for FY75 are given in Table A-10.

Drinking Water

Drinking water monitoring consists of 77 quarterly drinking water samples taken from major population centers and selected nuclear facility environs.

The analyses performed for the drinking water are currently being evaluated with respect to the Safe Drinking Water Act of 1974 and will be expanded to meet requirements of that legislation. Those analyses which may be added include strontium-89, radium-226, cesium-134 and cesium-137.

The results of tritium in drinking water analyses for FY75 are shown in Table A-11.

Analyses for gross alpha beta, strontium-90 and radium-226 are shown in Table A-12.

Results of analyses for plutonium and uranium in selected drinking water samples for FY75 are shown in Table A-13.

Table A-10

Surface Water

Tritium Concentration

(nCi/l)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AL:Decatur	4	.4	.3
Gordon	4	.8	.3
AR:Little Rock	4	.2	.1
CA:Clay Station	4	.2	.1
Diablo Canyon	4	.0	.0
Eureka	1	5.	5.
San Onofre	4	.2	.1
CO:Greeley	4	.7	.6
CT:East Haddam	4	1.6	.5
Waterford	4	.3	.2
FL:Crystal River	4	.2	.1
Ft. Pierce	4	.1	.0
Homestead	4	1.7	.9
GA:Baxley	2	.1	.1
IA:Cedar Rapids	3	.5	.3
ID:Buhl	4	.4	.4
IL:Moline	4	.5	.3
Morris	4	.3	.2
Zion	4	.3	.2
LA:New Orleans	4	.2	.1
MA:Plymouth	4	.3	.2
Rowe	4	.3	.2
MD:Conowingo	4	.3	.2
Lusby	4	.3	.2
ME:Wiscasset	4	.4	.3
MI:Bridgman	4	.5	.3
Charlevoix	4	.3	.3
Monroe	4	.4	.3
South Haven	4	.4	.3
MN:Monticello	4	.5	.4
Red Wing	4	.4	.4

Table A-10 (Continued)

Location	No. of Samples	Max	Avg
NC:Charlotte	4	.4	.3
Southport	4	.2	.1
NE:Rulo	4	.6	.5
NJ:Bayside	3	.2	.1
Oyster Creek	4	.2	.2
NV:Boulder City	4	.5	.5
NY:Ossining	4	.4	.2
Oswego	4	.4	.4
Poughkeepsie	4	.3	.2
OH:Toledo	NS		
OR:Westport	3	.2	.1
SC:Allendale	4	5.9	3.7
Hartsville	4	3.3	2.1
TN:Daisy	4	.5	.4
Kingston	4	2.6	1.0
TX:El Paso	4	.3	.2
VA:Mineral	4	.3	.3
Newport News	3	.3	.2
VT:Vernon	4	.2	.2
WA:Northport	4	.5	.4
Richland	4	.6	.5
WI:Two Creeks	4	1.0	.5
Victory	4	.3	.3
WV:Wheeling	4	.3	.2
NETWORK SUMMARY	207	5.9	.47

NS, no sample.

Table A-11

Drinking Water

Tritium Concentration

(nCi/l)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
AK:Anchorage	4	.6	0.5
Fairbanks	4	.5	.4
AL:Dothan	4	.0	.0
Montgomery	4	.2	.1
Muscle Shoals	4	.3	.3
AR:Little Rock	4	.2	.1
CA:Berkeley	4	.2	.1
Los Angeles	4	.1	.0
CO:Denver	4	.6	.4
Platteville	4	.9	.7
CT:Hartford	4	.2	.1
CZ:Ancon	4	.1	.1
DC:Washington	4	.3	.2
DE:Wilmington	4	.3	.2
FL:Miami	4	.1	.1
Tampa	4	.1	.1
GA:Baxley	3	.1	.1
Savannah	4	3.0	2.6
HI:Honolulu	4	.0	.0
IA:Cedar Rapids	4	.5	.3
ID:Boise	3	.2	.2
Idaho Falls	4	.6	.5
IL:Morris	4	.1	.0
Chicago	4	.3	.2
KS:Topeka	4	.3	.2
LA:New Orleans	4	.3	.2
MA:Lawrence	4	.2	.2
Rowe	3	.4	.2
MD:Baltimore	4	.5	.3
Conowingo	4	.3	.3
ME:Augusta	4	.2	.1
MI:Detroit	4	.4	.3
Grand Rapids	4	.3	.3
MN:Minneapolis	4	.5	.5
Red Wing	4	.1	.0

Table A-11 (Continued)

Location	No. of Samples	Max	Avg
MO:Jefferson City	4	.2	.1
MS:Jackson	4	.2	.1
MT:Helena	4	.4	.4
NC:Charlotte	4	.3	.3
Wilmington	4	.3	.2
ND:Bismarck	4	.7	.5
NE:Lincoln	4	.2	.1
NH:Concord	4	.3	.2
NJ:Trenton	4	.4	.2
Waretown	4	.1	.0
NM:Santa Fe	3	.5	.3
NV:Las Vegas	4	.7	.6
NY:Albany	4	.3	.2
New York	2	.3	.2
Buffalo	4	.5	.4
Syracuse	4	.8	.6
OH:Cincinnati	4	.2	.2
East Liverpool	4	.4	.3
Painesville	4	.5	.4
Toledo	1	.3	.3
OK:Oklahoma City	2	.2	.1
OR:Portland	4	.3	.1
PA:Columbia	4	.7	.3
Harrisburg	4	.3	.2
Pittsburgh	4	.3	.3
PR:San Juan	4	.1	.0
RI:Providence	4	.2	.1
SC:Anderson	4	.4	.3
Columbia	4	.4	.3
Hartsville	4	.2	.1
Seneca	4	.3	.3
TN:Chattanooga	4	.4	.3
Knoxville	4	.3	.2
TX:Austin	4	.1	.1
VA:Doswell	4	.2	.1
Lynchburg	4	.2	.2
Norfolk	4	.2	.2
WA:Richland	4	.6	.5
Seattle	4	.4	.2
WI:Genoa	3	.0	.0
Madison	4	.3	.1
NETWORK SUMMARY	292	3.0	.25

Table A-12

Drinking Water

Gross Alpha, Beta Concentration

April - June 1975

Annual Analysis

				Indicated Activity in pCi/l			
Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
AK:Anchorage	4/14/75	94.0	(e) 4/24/75	(e) 4/25/75			(d)
Fairbanks	4/08/75	78.0	1.3 ± 0.9 4/28/75	(e) 4/28/75			(d)
AL:Dothan	4/04/75	82.0	1.4 ± 0.9 4/28/75	(e) 4/28/75			(d)
Montgomery	4/04/75	62.6	1.3 ± 0.9 4/22/75	(e) 4/22/75			(d)
Muscle Shoals	4/03/75	60.0	2.6 ± 1.0 4/22/75	(e) 4/22/75			(d)
AR:Little Rock	4/03/75	36.0	1.7 ± 0.9 4/24/75	(e) 4/25/75			(d)
CA:Berkeley	4/02/75	46.0	1.4 ± 0.9 4/28/75	(e) 4/28/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
Los Angeles	4/01/75	108.0	3.7 ± 1.1 4/25/75	(e) 4/23/75			(d)
CO:Denver	4/03/75	58.6	1.1 ± 1.0 4/28/75	(e) 4/28/75			(d)
Platteville	4/03/75	880.0	3.0 ± 1.0 5/09/75	(e) 5/09/75			(d)
CT:Hartford	4/02/75	36.0	1.6 ± 0.9 4/22/75	(e) 4/22/75			(d)
CZ:Ancon	4/21/75	72.0	(e) 5/12/75	(e) 5/09/75			(d)
DC:Washington	4/09/75	98.0	2.3 ± 0.9 6/04/75	(e) 6/04/75			(d)
DE:Wilmington	4/02/75	27.0	2.1 ± 1.0 4/24/75	(e) 4/24/75			(d)
FL:Miami	4/01/75	216.8	1.8 ± 1.1 4/22/75	(e) 4/22/75			(d)
Tampa	4/15/75	310.0	2.2 ± 1.1 4/25/75	(e) 4/25/75			(d)
GA:Baxley	4/01/75	186.6	5.6 ± 1.4 4/22/75	5.5 ± 1.8 4/22/75		3.1 ± .1	(d)
Savannah	4/01/75	64.0	1.6 ± 0.2 4/22/75	(e) 4/22/75			(d)
HI:Honolulu	4/14/75	244.0	2.3 ± 1.0 4/25/75	(e) 4/25/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
IA:Cedar Rapids	4/02/75	167.4	2.6 ± 1.1 4/25/75	(e) 4/25/75			(d)
ID:Boise	4/02/75	46.0	(e) 4/25/75	(e) 4/25/75			(d)
Idaho Falls	4/04/75	120.0	2.3 ± 1.0 4/28/75	(e) 4/25/75			(d)
IL:Morris	4/02/75	378.0	29.4 ± 2.6 4/28/75	16.4 ± 3.4 4/28/75	(e)	7.4 ± .1	755±159 04/23/75
Chicago	4/01/75	734.0	1.1 ± 0.9 4/22/75	(e) 4/22/75			(d)
KS:Topeka	4/01/75	418.0	4.4 ± 1.3 4/24/75	(e) 4/25/75			(d)
LA:New Orleans	5/09/75	100.0	1.9 ± 0.9 5/15/75	(e) 5/15/75			(d)
MA:Lawrence	4/01/75	92.0	1.4 ± 1.0 4/25/75	(e) 4/25/75			(d)
Rowe	5/14/75	104.0	1.8 ± 0.9 6/04/75	(e) 6/04/75			(d)
MD:Baltimore	4/02/75	90.0	2.0 ± 1.6 4/24/75	(e) 4/25/75			(d)
Conowingo	4/01/75	154.0	1.6 ± 0.9 4/25/75	(e) 4/24/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
ME:Augusta	4/02/75	10.0	1.5 ± 1.0 4/25/75	(e) 4/24/75			(d)
MI:Detroit	4/07/75	146.0	2.7 ± 1.1 4/25/75	(e) 4/24/75			(d)
Grand Rapids	4/01/75	188.0	2.4 ± 1.1 4/22/75	(e) 4/22/75			(d)
MN:Minneapolis	4/04/75	122.0	2.4 ± 1.0 4/28/75	(e) 4/25/75			(d)
Red Wing	4/04/75	644.0	18.7 ± 2.2 4/28/75	(e) 4/25/75	(e)		(d)
MO:Jefferson City	4/04/75	640.0	7.9 ± 1.7 5/21/75	(e) 5/20/75			(d)
MS:Jackson	4/02/75	66.0	1.7 ± 1.0 4/22/75	(e) 4/22/75			(d)
MT:Helena	4/08/75	48.6	1.4 ± 1.1 4/28/75	(e) 4/28/75			(d)
NC:Charlotte	4/02/75	46.6	1.1 ± 0.9 4/25/75	(e) 4/25/75			(d)
Wilmington	6/05/75	48.0	2.3 ± 0.9 6/25/75	(e) 6/25/75			(d)
ND:Bismarck	4/04/75	310.0	2.8 ± 1.1 4/28/75	(e) 4/28/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
NE:Lincoln	4/10/75	312.0	10.2 ± 1.6 4/25/75	3.7 ± 1.7 4/25/75	(e)	0.3 ± .02	(d)
NH:Concord	4/01/75	282.0	1.2 ± 1.1 5/09/75	(e) 5/09/75			(d)
NJ:Trenton	4/30/75	134.0	4.5 ± 1.1 5/15/75	(e) 5/15/75			(d)
Waretown	4/10/75	64.0	3.5 ± 1.1 4/25/75	(e) 4/25/75			(d)
NM:Santa Fe	4/01/75	78.0	2.2 ± 0.9 4/25/75	(e) 4/24/75			(d)
NV:Las Vegas	4/01/75	798.0	11.5 ± 2.1 4/28/75	(e) 4/28/75	1.7 ± 0.8		(d)
NY:Albany	4/02/75	66.8	1.7 ± 0.9 4/22/75	(e) 4/22/75			(d)
Buffalo	4/01/75	70.0	2.8 ± 1.0 4/24/75	(e) 4/25/75			(d)
New York	(f)						
Syracuse	5/30/75	68.0	1.8 ± 0.9 6/24/75	(e) 6/24/75			(d)
OH:Cincinnati	4/01/75	194.0	2.7 ± 1.2 4/22/75	(e) 4/22/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Ctd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
Columbus	(g)						
East Liverpool	4/22/75	266.0	3.3 ± 1.1 5/09/75	(e) 5/09/75			(d)
Painesville	4/01/75	134.0	2.9 ± 1.1 4/25/75	(e) 4/25/75			(d)
Toledo	5/05/75	682.0	3.2 ± 1.2 5/21/75	(e) 5/20/75			(d)
OK:Oklahoma	(f)						
OR:Portland	4/02/75	26.0	(e) 4/28/75	(e) 4/28/75			(d)
PA:Columbia	4/01/75	138.2	1.7 ± 1.0 4/25/75	(e) 4/25/75			(d)
Harrisburg	4/01/75	34.0	1.2 ± 0.9 4/25/75	(e) 4/24/75			(d)
Pittsburgh	4/22/75	174.8	2.3 ± 1.1 5/09/75	(e) 5/09/75			(d)
PR:San Juan	4/11/75	164.0	3.1 ± 1.1 4/28/75	(e) 4/25/75			(d)
RI:Providence	4/04/75	79.0	2.7 ± 1.0 4/25/75	(e) 4/25/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
SC:Anderson	4/09/75	76.0	2.2 ± 0.9 5/15/75	(e) 5/15/75			(d)
Columbia	4/03/75	52.0	1.1 ± 0.7 5/15/75	(e) 5/15/75			(d)
Hartsville	4/03/75	21.0	(e) 5/15/75	(e) 5/15/75			(d)
Seneca	4/09/75	26.0	(e) 5/15/75	(e) 5/15/75			(d)
TN:Chattanooga	4/01/75	74.0	2.1 ± 0.9 4/22/75	(e) 4/22/75			(d)
Knoxville	4/01/75	106.0	2.9 ± 1.0 4/22/75	(e) 4/22/75			(d)
TX:Austin	4/02/75	180.0	3.1 ± 1.2 4/25/75	(e) 4/25/75			(d)
VA:Doswell	4/03/75	158.0	3.6 ± 1.2 4/28/75	(e) 4/28/75			(d)
Lynchburg	4/01/75	40.0	1.5 ± 0.9 4/25/75	(e) 4/24/75			(d)
Norfolk	4/01/75	86.0	2.9 ± 1.0 4/22/75	(e) 4/22/75			(d)
WA:Richland	4/08/75	96.0	1.3 ± 0.9 4/25/75	(e) 4/25/75			(d)

Table A-12 (Continued)

Location	Date Collected	Total Solids mg/l	Gross Beta Date Dtd. (a)(b)	Gross Alpha Date Ctd. (a)(c)	^{90}Sr	^{226}Ra	Specific Gamma Activity
Seattle	4/01/75	40.0	(e) 4/28/75	(e) 4/28/75			(d)
WI:Genoa	4/03/75	196.0	2.3 ± 1.1 4/28/75	(e) 4/28/75			(d)
Madison	4/01/75	414.0	3.0 ± 1.2 4/24/75	(e) 4/25/75			(d)
Network Average			2.95	0.34			

(a) The error expressed is the 2-sigma counting error.
(b) The minimum detectable limit of gross alpha is 2.0 pCi/l.
(c) The minimum detectable limit of gross beta is 1.0 pCi/l.
(d) Indicates specific gamma activity not detectable.
(e) Indicates activity not detectable.
(f) No sample.
(g) Newly established sampling sites. Data will appear in future issues.

Table A-13

Plutonium and Uranium Analyses
of
Selected Drinking Water Samples
July 1974 - June 1975

Location	Plutonium (pCi/l)	Uranium (pCi/l)
AL:Montgomery	238Pu .008±.005	234U .039±.012
	239Pu .022±.009	235U .002±.003
		238U .036±.011
CA:Berkeley	238Pu 0	234U .013±.006
	239Pu .004±.004	235U 0
		238U .008±.004
Los Angeles	238Pu .001±.002	234U 1.99±0.24
	239Pu .006±.005	235U .086±.018
		238U 1.72±0.21
CO:Denver	238Pu .003±.003	234U .160±.027
	239Pu .012±.008	235U .005±.004
		238U .109±.021
ID:Idaho Falls	238Pu 0	234U .800±.112
	239Pu .005±.004	235U .030±.010
		238U .436±.065
IL:Chicago	238Pu 0	234U .080±.018
	239Pu .001±.002	235U .004±.004
		238U .072±.017
ND:Bismarck	238Pu .003±.003	234U .253±.038
	239Pu .009±.006	235U .011±.006
		238U .149±.027
NM:Santa Fe	238Pu 0	234U 2.49±.320
	239Pu .009±.007	235U .060±.015
		238U .853±.119
NV:Las Vegas	238Pu .006±.007	234U 2.49±.320
	239Pu .023±.014	235U .138±.028
		238U 1.57±.220
NY:Buffalo	238Pu .001±.002	234U .080±.016
	239Pu .003±.003	235U .006±.004
		238U .074±.027

Table A-13 (Continued)

Location	Plutonium (pCi/l)	Uranium (pCi/l)
New York City	238Pu .003±.003	234U .010±.005
	239Pu .009±.006	235U .001±.002
		238U .005±.004
OH:Cincinnati	238Pu .005±.004	234U .006±.004
	239Pu .009±.006	235U .001±.002
		238U .007±.004
OK:Oklahoma City	238Pu .004±.004	234U .025±.009
	239Pu .009±.006	235U .001±.002
		238U .014±.006
OR:Portland	238Pu 0	234U .009±.005
	239Pu .005±.004	235U .001±.002
		238U .004±.003
PA:Harrisburg	238Pu 0	234U .006±.004
	239Pu .003±.003	235U .003±.003
		238U .005±.003
Pittsburgh	238Pu 0	234U .025±.009
	239Pu 0	235U .001±.002
		238U .016±.007
SC:Anderson	238Pu .001±.002	234U .009±.005
	239Pu .006±.004	235U .001±.002
		238U .008±.004
Columbia	238Pu 0	234U .014±.006
	239Pu .004±.003	235U .001±.002
		238U .010±.005
TN:Knoxville	238Pu .006±.005	234U .078±.016
	239Pu .008±.005	235U .007±.004
		238U .059±.013
VA:Lynchburg	238Pu 0	234U .010±.005
	239Pu .004±.003	235U .001±.002
		238U .011±.006
NETWORK AVERAGES	238Pu .002	234U .429
	239Pu .008	235U .018
		238U .258

SECTION III. Milk Program

Pasteurized Milk

Pasteurized milk monitoring consists of 65 nationwide sampling sites which contribute monthly pasteurized milk samples. These samples are analyzed for iodine-131, barium-140, cesium-137, and potassium. All 65 samples are analyzed annually for strontium-89 and strontium-90. The annual average value for strontium-89 was .3 and for strontium-90 the annual average value was 4.2.

The values from the pasteurized milk samples for the period FY75 are shown in Tables A-14 through A-17.

The results of analyses of regional composite samples for strontium-89 are shown in Table A-18. Table A-19 shows the results of analyses of regional composite samples for strontium-90.

Table A-14

131 I in Pasteurized Milk

(pCi/l)

July 1974 - June 1975

Station	No. of Samples	Max	Avg
AK:Palmer	2	0	.0
AL:Montgomery	12	3	.7
AR:Little Rock	12	4	.8
AZ:Phoenix	12	0	.0
CA:Los Angeles	12	2	.3
San Francisco	12	9	1.2
Sacramento	9	4	1.0
CO:Denver	12	4	.5
CT:Hartford	12	3	.8
CZ:Cristobal	12	9	1.8
DC:Washington	12	3	.7
DE:Wilmington	11	6	1.6
FL:Tampa	11	5	.8
GA:Atlanta	9	7	1.1
HI:Honolulu	12	2	.4
IA:Des Moines	12	4	1.0
ID:Idaho Falls	12	3	.5
IL:Chicago	12	3	.8
IN:Indianapolis	12	5	.9
KS:Wichita	12	4	.8
KY:Louisville	12	5	.9
LA:New Orleans	12	3	.7
MA:Boston	12	3	.5
MD:Baltimore	12	5	1.0
ME:Portland	12	8	1.3
MI:Detroit	12	5	.8
Grand Rapids	12	4	.3
MN:Minneapolis	12	8	1.2
MO:Kansas City	11	3	.7
St. Louis	12	8	1.4
MS:Jackson	12	4	.7
MT:Helena	9	2	.2
NC:Charlotte	12	5	.7
ND:Minot	12	4	.8
NE:Omaha	11	2	.5
NH:Manchester	12	2	.3

Table A-14 (Continued)

Station	No. of Samples	Max	Avg
NJ:Trenton	10	2	.8
NM:Albuquerque	12	4	1.2
NV:Las Vegas	11	4	.5
NY:Buffalo	12	5	.8
New York	12	2	.5
Syracuse	12	4	.8
OH:Cincinnati	12	3	.3
OH:Cleveland	12	5	1.6
OK:Oklahoma City	12	4	1.1
OR:Portland	12	4	1.2
PA:Philadelphia	12	3	.8
Pittsburgh	12	7	1.1
PR:San Juan	12	3	.7
RI:Providence	12	4	.4
SC:Charleston	12	2	.5
SD:Rapid City	11	2	.5
TN:Chattanooga	12	3	.4
Knoxville	12	4	.8
Memphis	12	7	.6
TX:Austin	12	3	.5
Dallas	11	5	.8
UT:Salt Lake City	12	5	1.3
VA:Norfolk	12	2	.5
VT:Burlington	12	8	1.3
WA:Seattle	12	4	.8
Spokane	12	4	.7
WI:Milwaukee	12	6	1.1
WV:Charleston	12	4	1.2
WY:Laramie	12	2	.6
NETWORK SUMMARY	752	9	.8

Table A-15

140 Ba in Pasteurized Milk

(pCi/l)

July 1974 - June 1975

Station	No. of Samples	Max	Avg
AK:Palmer	2	0	.0
AL:Montgomery	12	0	.0
AR:Little Rock	12	0	.0
AZ:Phoenix	12	1	.1
CA:Los Angeles	12	0	.0
San Francisco	12	0	.0
Sacramento	9	2	.4
CO:Denver	12	0	.0
CT:Hartford	12	0	.0
CZ:Cristobal	12	6	.5
DC:Washington	12	0	.0
DE:Wilmington	11	0	.0
FL:Tampa	11	1	.1
GA:Atlanta	9	0	.0
HI:Honolulu	12	0	.0
IA:Des Moines	12	3	.3
ID:Idaho Falls	12	0	.0
IL:Chicago	12	0	.0
IN:Indianapolis	12	0	.0
KS:Wichita	12	0	.0
KY:Louisville	12	0	.0
LA:New Orleans	12	1	.1
MA:Boston	12	0	.0
MD:Baltimore	12	0	.0
ME:Portland	12	0	.0
MI:Detroit	12	1	.1
MI:Grand Rapids	12	0	.0
MN:Minneapolis	12	4	.5
MO:Kansas City	11	2	.4
St. Louis	12	3	.4
MS:Jackson	12	4	.3
MT:Helena	9	3	.3
NC:Charlotte	12	1	.1
ND:Minot	12	3	.3
NE:Omaha	11	3	.3
NH:Manchester	12	1	.1

Table A-15 (Continued)

Station	No. of Samples	Max	Avg
NJ:Trenton	10	0	.0
NM:Albuquerque	12	0	.0
NV:Las Vegas	11	0	.0
NY:Buffalo	12	9	.8
New York	12	3	.3
Syracuse	12	0	.0
OH:Cincinnati	12	9	.8
Cleveland	12	0	.0
OK:Oklahoma City	12	5	.7
OR:Portland	12	9	1.1
PA:Philadelphia	12	1	.1
Pittsburgh	12	0	.0
PR:San Juan	12	1	.1
RI:Providence	12	1	.1
SC:Charleston	12	1	.1
SD:Rapid City	11	9	.9
TN:Chattanooga	12	5	.4
Knoxville	12	0	.0
Memphis	12	2	.2
TX:Austin	12	2	.2
Dallas	11	1	.1
UT:Salt Lake City	12	0	.0
VA:Norfolk	12	0	.0
VT:Burlington	12	0	.0
WA:Seattle	12	1	.3
Spokane	12	2	.3
WI:Milwaukee	12	1	.1
WV:Charleston	12	0	.0
WY:Laramie	12	0	.0
NETWORK SUMMARY	752	9	.2

Table A-16

137 Cs in Pasteurized Milk

(pCi/l)

July 1974 - June 1975

Station	No. of Samples	Max	Avg
AK:Palmer	2	19	12.0
AL:Montgomery	12	17	10.3
AR:Little Rock	12	17	10.3
AZ:Phoenix	12	10	4.7
CA:Los Angeles	12	8	4.9
San Francisco	12	9	4.7
Sacramento	9	13	6.2
CO:Denver	12	13	6.1
CT:Hartford	12	15	10.3
CZ:Cristobal	12	8	5.2
DC:Washington	12	18	8.6
DE:Wilmington	11	13	8.2
FL:Tampa	11	32	27.8
GA:Atlanta	9	18	13.8
HI:Honolulu	12	9	6.3
IA:Des Moines	12	15	10.0
ID:Idaho Falls	12	10	6.0
IL:Chicago	12	15	10.0
IN:Indianapolis	12	13	9.6
KS:Wichita	12	12	8.3
KY:Louisville	12	11	7.3
LA:New Orleans	12	18	11.9
MA:Boston	12	18	11.9
MD:Baltimore	12	13	8.9
ME:Portland	12	31	17.1
MI:Detroit	12	16	10.1
Grand Rapids	12	17	11.6
MN:Minneapolis	12	17	12.1
MO:Kansas City	11	18	9.3
St. Louis	12	14	9.0
MS:Jackson	12	13	9.4
MT:Helena	9	15	8.8
NC:Charlotte	12	13	9.4
ND:Minot	12	12	8.6
NE:Omaha	11	11	8.8
NH:Manchester	12	20	13.5

Table A-16 (Continued)

Station	No. of Samples	Max	Avg
NJ:Trenton	10	15	9.3
NM:Albuquerque	12	10	5.4
NV:Las Vegas	11	14	5.4
NY:Buffalo	12	15	9.6
New York	12	13	9.8
Syracuse	12	18	10.3
OH:Cincinnati	12	11	8.8
Cleveland	12	23	10.2
OK:Oklahoma City	12	15	8.3
Portland	12	12	6.6
PA:Philadelphia	12	11	7.9
Pittsburgh	12	16	9.7
PR:San Juan	12	12	7.1
RI:Providence	12	19	12.4
SC:Charleston	12	19	12.7
SD:Rapid City	11	20	10.1
TN:Chattanooga	12	11	9.1
Knoxville	12	13	7.8
Memphis	12	13	8.0
TX:Austin	12	9	5.9
Dallas	11	13	7.7
UT:Salt Lake City	12	18	7.6
VA:Norfolk	12	11	6.6
VT:Burlington	12	13	8.9
WA:Seattle	12	19	9.9
Spokane	12	18	10.5
WI:Milwaukee	12	15	9.9
WV:Charleston	12	12	8.1
WY:Laramie	12	9	3.8
NETWORK SUMMARY	752	32	9.1

Table A-17

Potassium in Pasteurized Milk

(g/1)

July 1974 - June 1975

Station	No. of Samples	Max	Avg
AK:Palmer	2	1.6	1.5
AL:Montgomery	12	1.6	1.5
AR:Little Rock	12	1.6	1.5
AZ:Phoenix	12	1.6	1.5
CA:Los Angeles	12	1.6	1.5
San Francisco	12	1.6	1.5
Sacramento	9	1.6	1.5
CO:Denver	12	1.6	1.4
CT:Hartford	12	1.6	1.5
CZ:Cristobal	12	1.6	1.5
DC:Washington	12	1.5	1.5
DE:Wilmington	11	1.6	1.5
FL:Tampa	11	1.6	1.5
GA:Atlanta	9	1.6	1.4
HI:Honolulu	12	1.6	1.5
IA:Des Moines	12	1.6	1.5
ID:Idaho Falls	12	1.6	1.5
IL:Chicago	12	1.6	1.5
IN:Indianapolis	12	1.5	1.4
KS:Wichita	12	1.6	1.5
KY:Louisville	12	1.5	1.4
LA:New Orleans	12	1.5	1.5
MA:Boston	12	1.6	1.5
MD:Baltimore	12	1.5	1.4
ME:Portland	12	1.5	1.4
MI:Detroit	12	1.5	1.4
Grand Rapids	12	1.6	1.5
MN:Minneapolis	12	1.6	1.5
MO:Kansas City	11	1.6	1.5
St. Louis	12	1.6	1.5
MS:Jackson	12	1.5	1.4
MT:Helena	9	1.5	1.5
NC:Charlotte	12	1.6	1.5
ND:Minot	12	1.6	1.5
NE:Omaha	11	1.6	1.4
NH:Manchester	12	1.7	1.5

Table A-17 (Continued)

Station	No. of Samples	Max	Avg
NJ:Trenton	10	1.6	1.5
NM:Albuquerque	12	1.5	1.4
NV:Las Vegas	11	1.5	1.5
NY:Buffalo	12	1.6	1.5
New York	12	1.6	1.5
Syracuse	12	1.6	1.5
OH:Cincinnati	12	1.6	1.5
Cleveland	12	1.6	1.5
OK:Oklahoma City	12	1.5	1.4
OR:Portland	12	1.6	1.5
PA:Philadelphia	12	1.5	1.5
Pittsburgh	12	1.5	1.4
PR:San Juan	12	1.5	1.5
RI:Providence	12	1.6	1.5
SC:Charleston	12	1.6	1.5
SD:Rapid City	11	1.6	1.5
TN:Chattanooga	12	1.6	1.4
Knoxville	12	1.5	1.5
Memphis	12	1.5	1.4
TX:Austin	12	1.6	1.5
Dallas	11	1.6	1.5
UT:Salt Lake City	12	1.7	1.5
VA:Norfolk	12	1.5	1.4
VT:Burlington	12	1.5	1.5
WA:Seattle	12	1.6	1.5
Spokane	12	1.5	1.4
WI:Milwaukee	12	1.6	1.5
WV:Charleston	12	1.6	1.5
WY:Laramie	12	1.6	1.4
NETWORK SUMMARY	752	1.7	1.5

Table A-18

Strontium 89 In Pasteurized Milk

(pCi/1)

Regional Composite Samples

July 1974 - June 1975

Region	No. of Samples	Max	Avg
I	3	1.0	.3
II	3	1.0	.3
III	3	3.0	1.
IV	3	0.0	0.
V	3	4.0	1.3
VI	3	4.0	1.3
VII	3	1.0	.3
VIII	3	0.0	0.
IX	3	1.0	.7
X	3	1.0	.3
NETWORK SUMMARY	30	4.0	.55

Table A-19

Strontium 90 in Pasteurized Milk

(pCi/l)

Regional Composite Samples

July 1974 - June 1975

Region	No. of Samples	Max	Avg
I	3	5.7	5.3
II	3	4.2	3.6
III	3	4.8	4.7
IV	3	5.3	4.8
V	3	4.5	4.2
VI	3	4.3	3.6
VII	3	4.2	3.4
VIII	3	4.6	3.5
IX	3	1.6	1.0
X	3	3.2	3.0
NETWORK SUMMARY	30	5.7	3.7

SECTION V. PAHO - Air and Milk Programs

An agreement was made in 1962 with the Pan American Health Organization (PAHO) to develop a collaborative program for furnishing assistance to health authorities in the Americas for developing programs of radiological health. The agreement provided limited quantities of essential equipment on a loan basis to PAHO needed to establish surveillance programs, and also provided the requisite laboratory services for analysis of air, milk, water, and other samples. Technical advice was given on research designs for radiological health programs. The PAHO programs are included organizationally as an ancillary function of the ERAMS.

Air analyses at the present time are 12 weekly samples. Results of the PAHO air analyses for FY75 are shown in Table A-20.

Pan American milk samples are analyzed for potassium, strontium-89, strontium-90, iodine-131, cesium-137, and barium-140. The results for strontium-89 are shown in Table A-21. These values may have been affected by the detonation by the Peoples Republic of China on June 17, 1974. The results for the strontium-90 analyses are shown in Table A-22 and potassium results are shown in Table A-23. The results for iodine-131, barium-140, and cesium-137 showed no detectable concentrations for this period.

Table A-20

Gross Beta Radioactivity in Pan American Surface Air

(pCi/m^3)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
CHILE:Santiago	312	5.05	.238
COLOMBIA:Bogota	199	5.82	.044
ECUADOR:Cuenca	145	18.1	.673
Guayaquil	201	3.32	.336
Quito	47	9.78	.422
PERU:Lima	65	2.58	.484
VENEZUELA:Caracas	47	.26	.042
GUYANA:Georgetown	11	.04	.010
BOLIVIA:La Paz	17	.02	.008
NETWORK SUMMARY	1044	18.1	.251

Table A-21

Strontium-89 in Pan American Milk

(pCi/l)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
Chile:Santiago	9	20	3.8
Colombia:Bogota	4	22	9.
Ecuador:Guayaquil	9	57	12.8
Venezuela:Caracas	12	6	1.
NETWORK SUMMARY	34	57	6.7

Note: In these averages, the ND's have been averaged as zero.

Table A-22

Strontium 90 in Pan American Milk

(pCi/1)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
Chile:Santiago	9	2.8	.82
Colombia:Bogota	4	1.9	.83
Ecuador:Guayaquil	9	4.0	1.59
Venezuela:Caracas	12	4.0	1.86
NETWORK SUMMARY	34	4.0	1.28

Note: In these averages, the ND's have been averaged as zero.

Table A-23

Potassium in Pan American Milk

(g/l)

July 1974 - June 1975

Location	No. of Samples	Max	Avg
Chile:Santiago	9	1.59	1.45
Colombia:Bogota	4	1.37	1.30
Ecuador:Guayaquil	9	1.48	1.31
Venezuela:Caracas	12	1.52	1.26
NETWORK SUMMARY	34	1.59	1.33